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Control of Plumbosolvency in Building Plumbing Supplies

by
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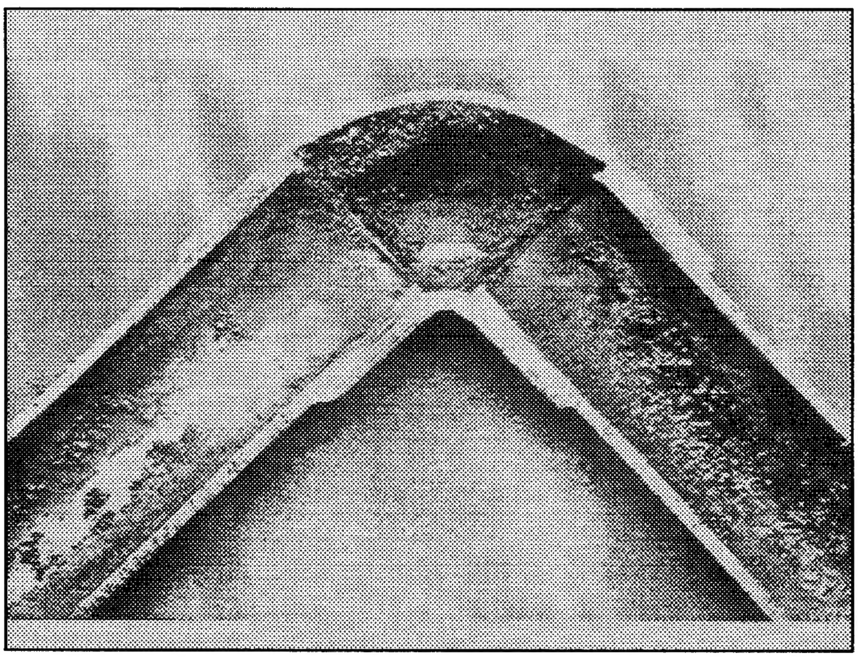

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This study evaluated the effectiveness of three chemical treatments versus a control for inhibiting lead corrosion under a variety of water quality parameters in both the laboratory and field. This study also tested whether a coating or lining could be applied, in-situ, to existing small diameter pipes or tubes to mitigate corrosion and plumbosolvency and eliminate the need for chemical treatment. Recommendations were made to incorporate the results of the chemical treatment study into existing Army guidance documents, and also to further study application of in-situ coatings.

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13. ABSTRACT (Maximum 200 words)

Army installations must comply with the increasingly stringent drinking water quality standards enacted at the Federal level and enforced by state regulations. Much attention has focused on the costly remediations required when the allowable level of lead in drinking water is exceeded. This issue plays a significant role in the search for cost-effective ways to ensure that drinking water at Army installations meets all standards for quality and compliance with applicable laws.

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Foreword

This study was conducted for U.S. Army Center for Public Works (USACPW) under Project 4A162784AT41, "Military Facilities Engineering Technology"; Work Unit 001BQ6, "Corrosion Control of Building Plumbing." The technical monitor was Malcolm McLeod, CECPW-ES.

The work was performed by the Materials Science and Technology Division (FL-M) of the Facilities Technology Laboratory (FL), U.S. Army Construction Engineering Research Laboratories (USACERL). The USACERL principal investigator was Vincent F. Hock. Kent Smothers is associated with the Illinois State Water Survey, Jane Anderson with the U.S. Army Center for Public Works, and Eric Zelsdorf with ECG, Inc. Ellen G. Segan is Acting Chief, CECER-FL-M; Donald F. Fournier is Acting Operations Chief, CECER-FL; and Dr. Alan W. Moore is Chief, CECER-FL. The USACERL technical editor was William J. Wolfe, Technical Resources Center.

COL James T. Scott is Commander and Dr. Michael J. O'Connor is Director of USACERL.

Note:

The following page inserts include figures referenced in DRAFT PWTB No. 420-46-07 (Appendix C to this report) that became available after publication of USACERL Technical Report 96/74.

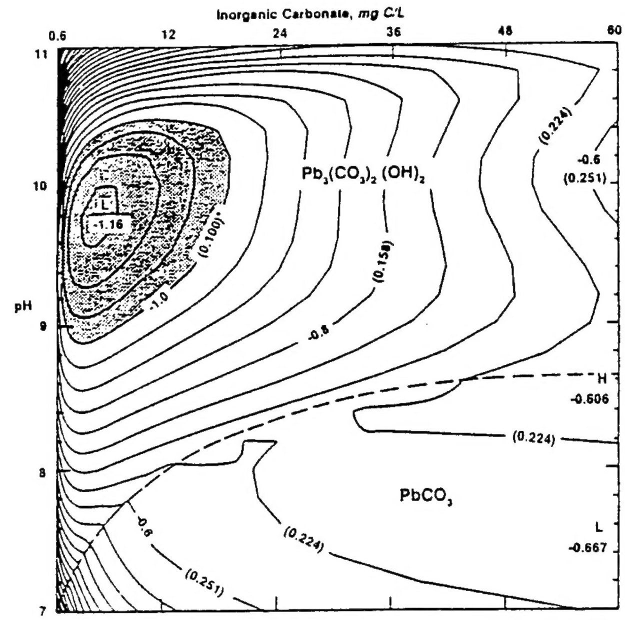

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Figure 1. Dissolved inorganic carbonate vs. pH: No phoshapte, I= 0.01, T = 25 °C.

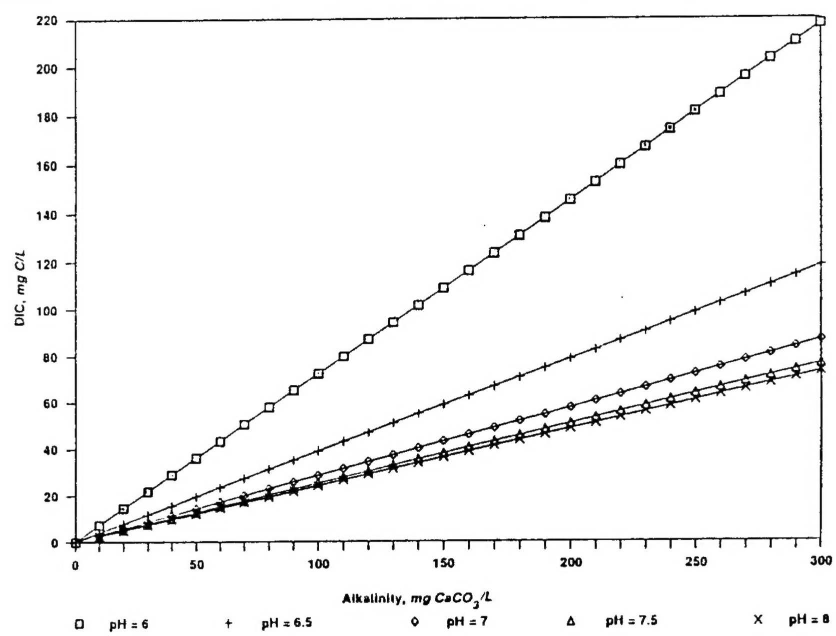

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Figure 2a. Relationship between alkalinity and DIC for various pH levels: pH = 6-8, I = 0.01, T = 25 °C.

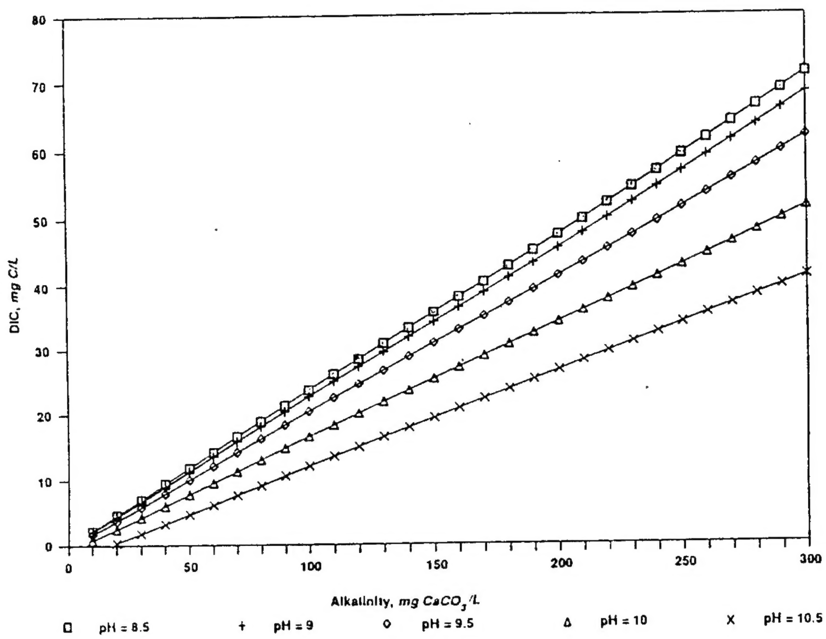

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Figure 2b. Relationship between alkalinity and DIC for various pH levels: pH = 8.5-10.5, I = 0.01, T = 25 °C.

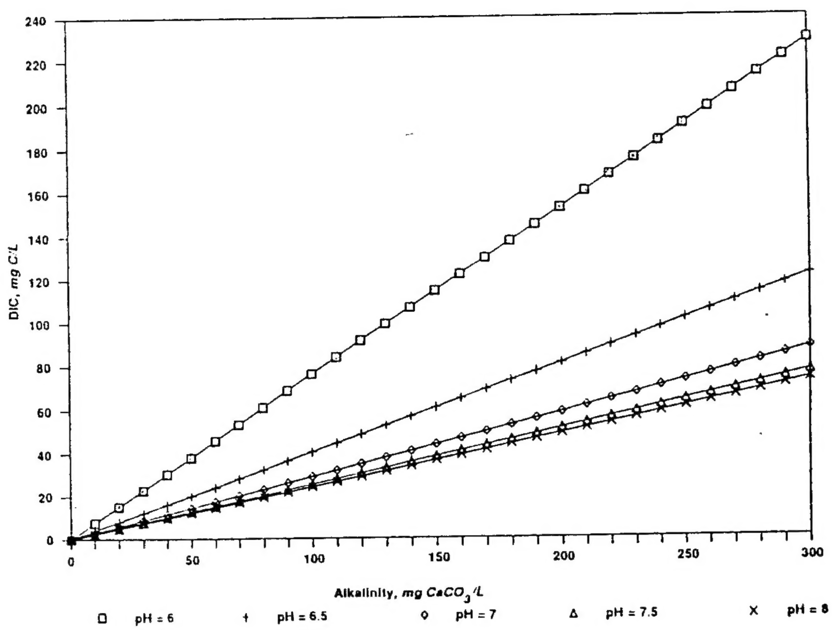

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Figure 2c. Relationship between alkalinity and DIC for various pH levels: pH = 6-8, I = 0.005, T = 25 °C.

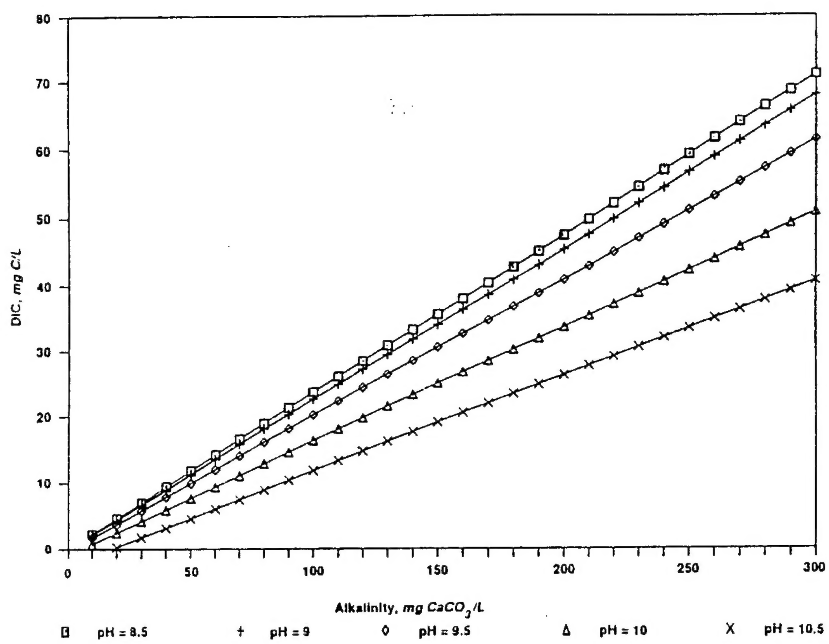

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Figure 2d. Relationship between alkalinity and DIC for various pH levels: pH = 8.5-10.5, I = 0.005, T = 25 °C.

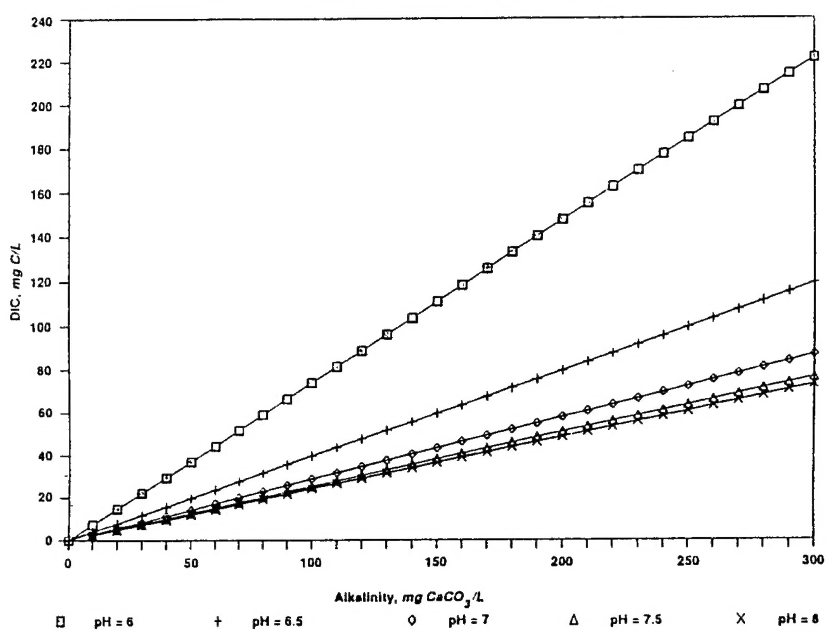

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Figure 2e. Relationship between alkalinity and DIC for various pH levels: pH = 6-8, I = 0.00075, T = 25 °C.

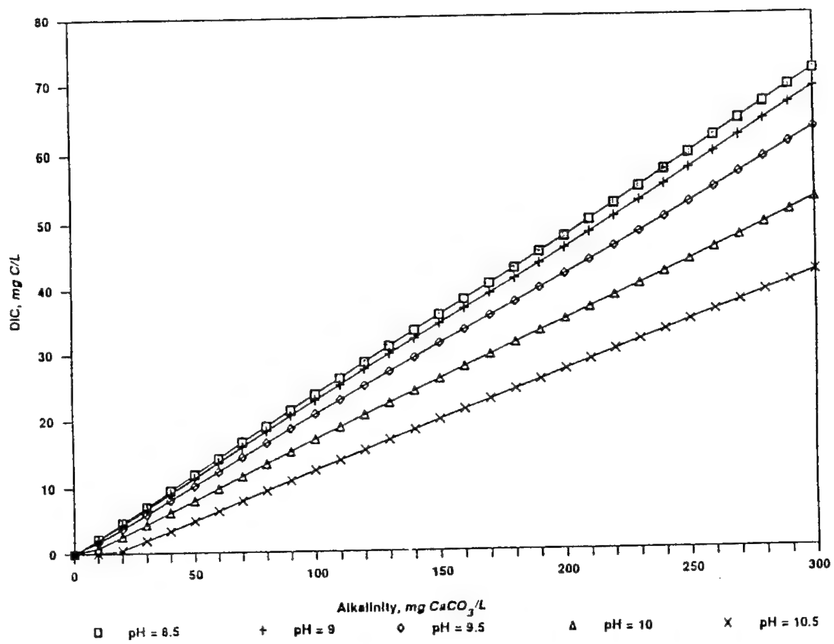

Figure 2f. Relationship between alkalinity and DIC for various pH levels: pH = 8.5-10.5, I = 0.00075, T = 25 °C.

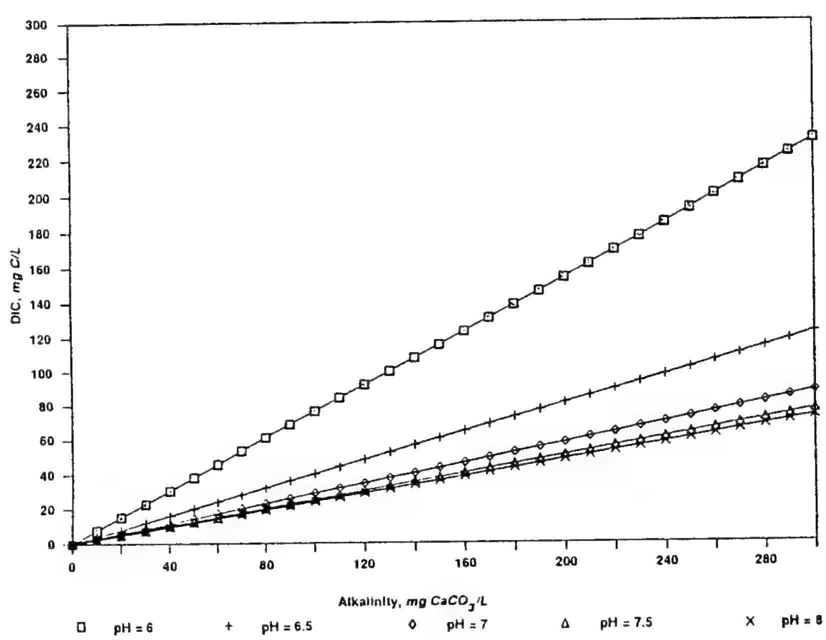

Figure 2g. Relationship between alkalinity and DIC for various pH levels: pH = 6-8, I = 0.00025, T = 25 °C.

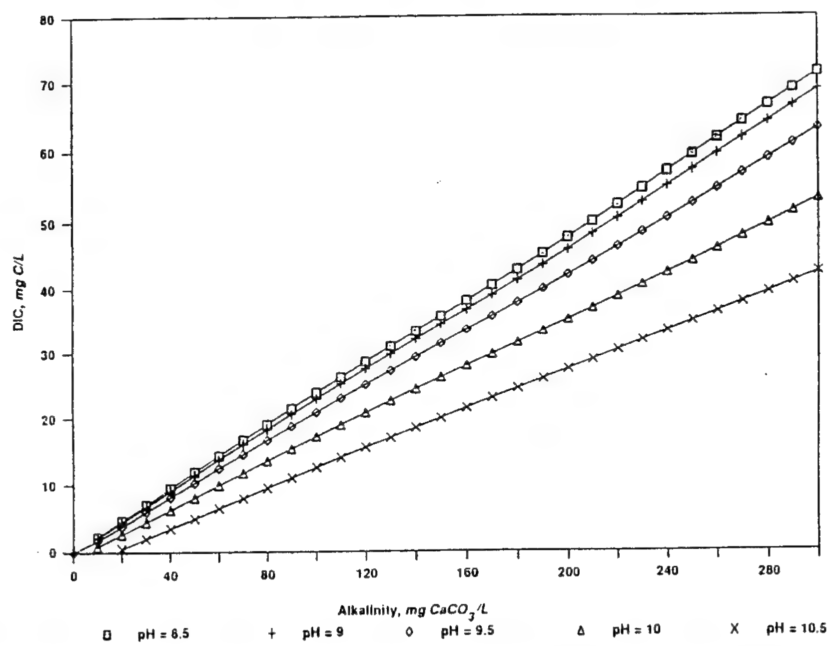

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Figure 2h. Relationship between alkalinity and DIC for various pH levels: pH = 8.5-10.5, I = 0.00025, T = 25 °C.

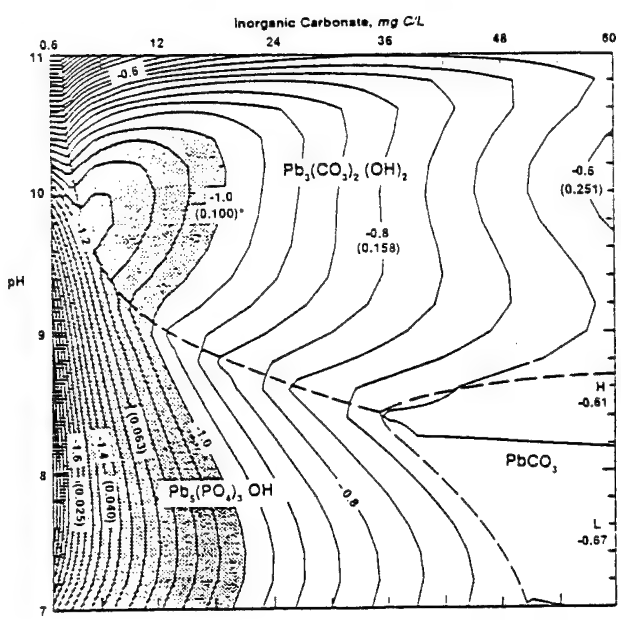

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Figure 3. Dissolved inorganic carbonate vs. pH: with phosphates = 0.5 mg PO_4/L, I = 0.005, T = 25 °C.

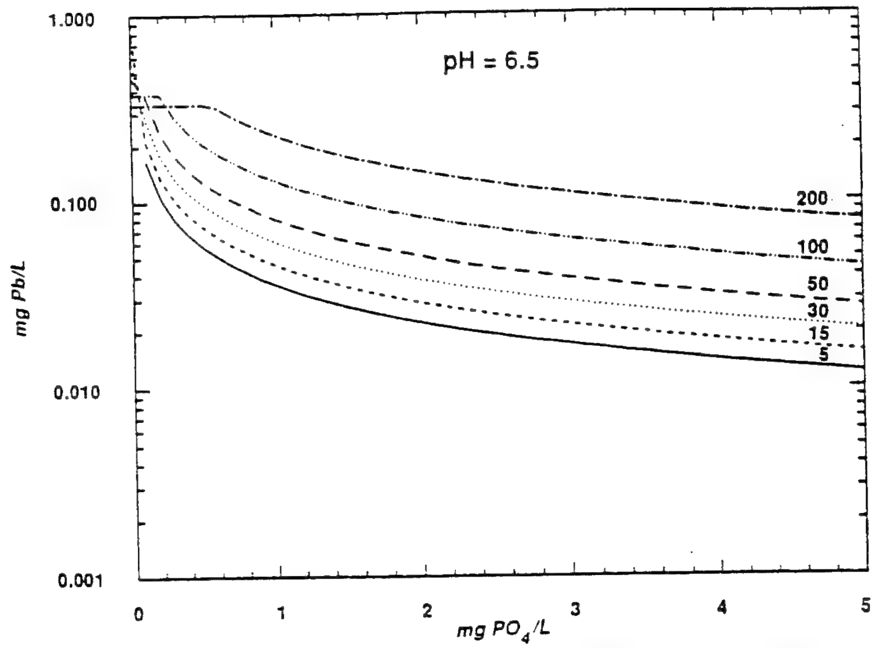

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Figure 4a. Lead solubility vs. orthophosphate at various alkalinities: pH = 6.5, I = 0.005, T = 25 °C.

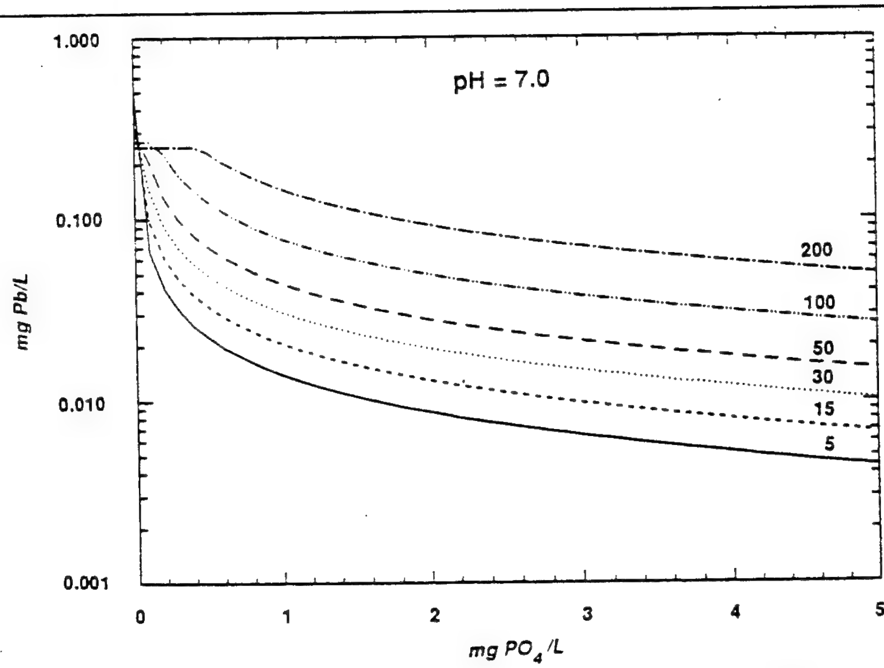

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Figure 4b. Lead solubility vs. orthophosphate at various alkalinities: pH = 7.0, I = 0.005, T = 25 °C.

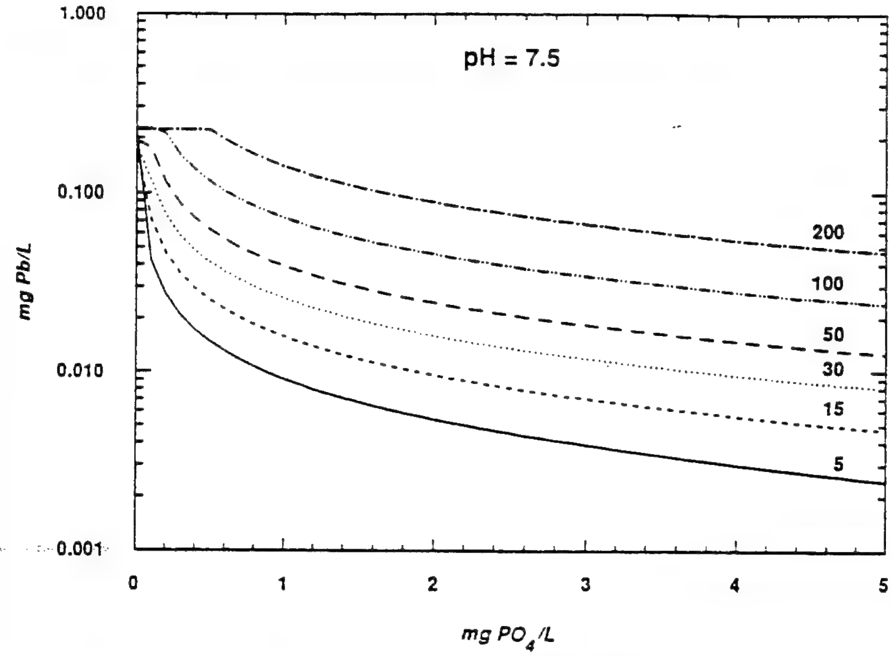

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Figure 4c. Lead solubility vs. orthophosphate at various alkalinities: pH = 7.5, I = 0.005, T = 25 °C.

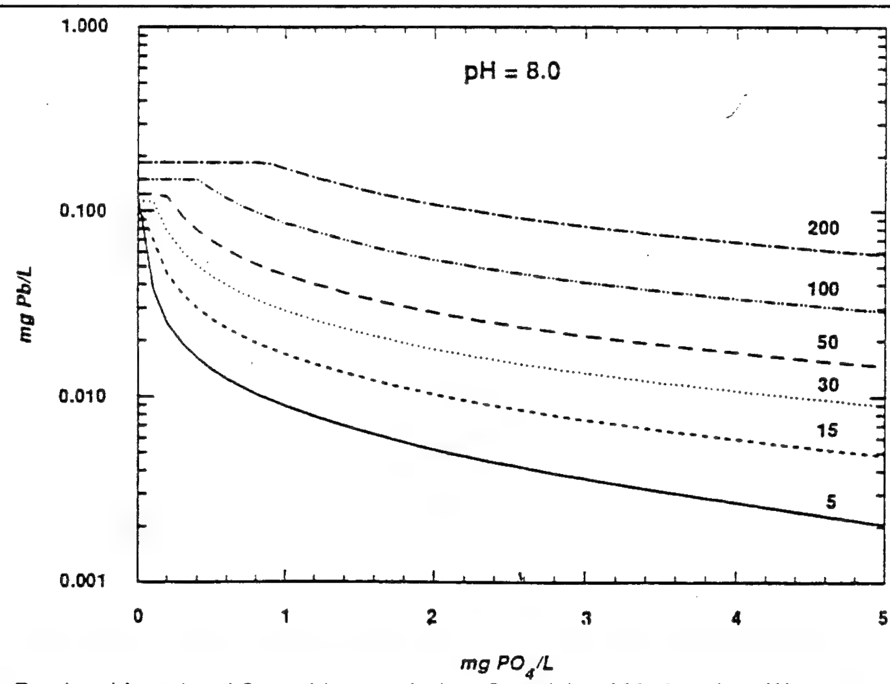

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Figure 4d. Lead solubility vs. orthophosphate at various alkalinities: pH = 8.0, I = 0.005, T = 25 °C.

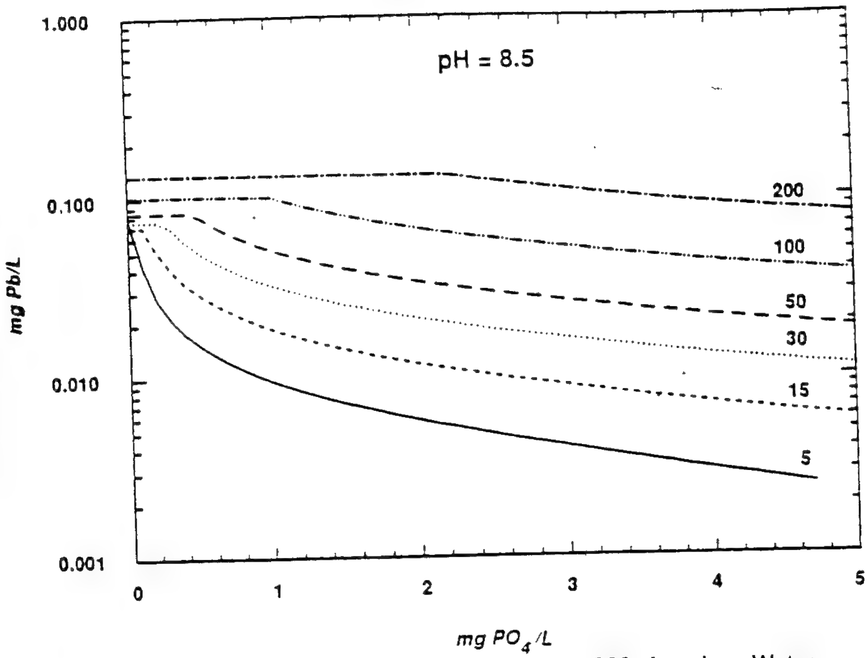

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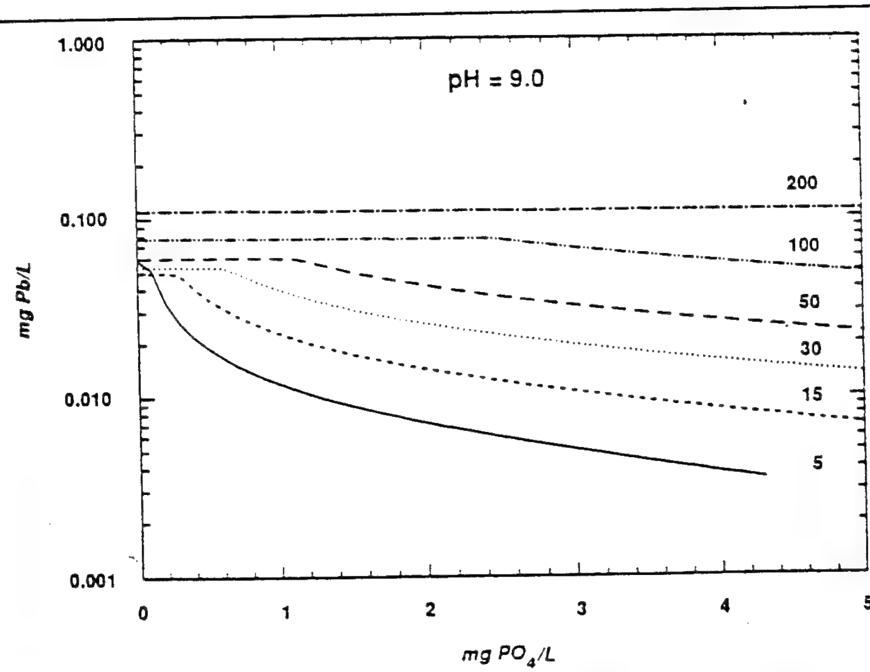
Figure 4e. Lead solubility vs. orthophosphate at various alkalinities: pH = 8.5, I = 0.005, T = 25 °C.



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1 Introduction

Background

Army installations must comply with the increasingly stringent drinking water quality standards enacted at the Federal level and enforced by state regulations. The Safe Drinking Water Act (SDWA) of 1974 required the U.S. Environmental Protection Agency (USEPA) to develop a list of maximum contaminant limits (MCLs) for inclusion in the National Primary Drinking Water Regulations (NPDWR) (Boffardi 1990). A September 1986 amendment to the SDWA went on to ban the use of lead in public water system pipes, solder, and flux (Cousino, Bacharach, and Heine 1987). On 7 June 1991, the USEPA finalized these regulations with a requirement of an MCL for lead concentration of 0.015 mg/L measured in the ninetieth percentile taken from cold water kitchen faucets following a 6- to 8-hour stagnation time (Boffardi 1993). In September 1992, the USEPA finished Volume II of the Lead and Copper Rule (LCR), which is the guidance manual on corrosion control treatment (USEPA 1992).

Much attention has focused on the costly remediations required when the lead action level is exceeded. This issue plays a significant role in the national debate over unfunded environmental mandates, and more specifically, in the search for cost-effective ways to ensure that drinking water at Army installations meets all standards for quality and compliance with applicable laws. Two possible strategies to ensure that drinking water meets current standards are by chemical treatment and by application of coatings or linings to pipes or tubes to mitigate corrosion or corrosion or plumbosolvency.

Objectives

The objectives of the this study were:

1. To evaluate the effectiveness of three chemical treatments versus a control for inhibiting lead corrosion under a variety of water quality parameters in both the laboratory and field.

2. To perform a laboratory investigation to validate the proof of principle that a coating or lining could be applied, in situ, to existing small diameter pipes or tubes to mitigate corrosion and plumbosolvency and eliminate the need for chemical treatment.

Approach

Experimental work conducted at USACERL examined two areas of lead control: inhibitor addition, and in-situ epoxy coating application. This work was complemented by a field study at Fort Meade, MD to investigate corrosion control strategies using corrosion inhibitors.

Static Water Quality Experiment

This study was conducted under static laboratory conditions to evaluate the effectiveness of three different chemical inhibitor blends in controlling plumbosolvency. Each of the three treatments was tested against a control for eight different water qualities. This static testing was conducted over a 4-week period and was concerned primarily with the inhibition of metal release into the water rather than corrosion rate measurements.

In-Situ Pipe Coating Experiment

The experimental procedures consisted of fabricating copper pipe and plastic pipe specimens, abrasively cleaning the interior surface followed by either blowing through or depositing the 100 percent solids epoxy coating. The epoxy coating was then air cured. The evaluation consisted simply of sectioning the specimens and measuring the coating thickness to determine uniformity of each application technique.

Corrosion Control Field Study

Based on a preliminary analysis of the water quality at the Fort Meade drinking water treatment plant, three groups of four ASTM/CERL pipe loop models were established to test water at the field test site. One group of models was installed at the water treatment plant, a second group was installed in a seldom used barracks approximately 5 miles from the treatment plant (a point in the distribution system that historically exhibited low chlorine residuals), and a third group was installed adjacent to a wellhead to test untreated well water. Within each group, one model tested a zinc orthophosphate/zinc potassium polyphosphate combination at a concentration of 3 to 5 mg/L (as orthophosphate), a second model tested a potassium monophosphate/

potassium tripolyphosphate combination at a concentration of 3 to 5 mg/L (as orthophosphate), a third model evaluated calcium hardness adjustment through pH/alkalinity modification using a pH of 8 and alkalinity between 60 and 70 mg/L (as $CaCO_3$), and a final model was operated as a control, i.e., no inhibitor or water quality adjustment. Concurrent with the addition of corrosion inhibitors at the wellhead, it was recommended that the pH be adjusted from 5.0 to 7.6 and the alkalinity (as $CaCO_3$) be adjusted from 10 mg/L to 60 mg/L. These loops were monitored for lead, copper, and iron concentrations in 8-hour standing samples, as well as for direct metal corrosion by means of coupons and inserts, for a period of 90 days. USEPA-approved analytical methods and quality assurance/quality control protocols were followed. (Analytical data are included in Appendixes A and B to this report.)

Mode of Technology Transfer

It is recommended that the results of this study be incorporated into the Draft Center for Public Works Technical Bulletin (PWTB) No. 420-46-07, *Chemical Treatment of Domestic Water to Inhibit Dissolution of Lead in Building Plumbing* (included as Appendix C to this report), and Corps of Engineers Guide Specification (CEGS) 15400, *Building Plumbing* and CEGS 15401, *Hospital Building Plumbing*.

2 Control Strategies for Plumbosolvency Mediation

Sources of Lead

Lead in water stems from a variety of sources, including: (1) lead pipe; (2) brass faucets, bronze fittings, and other fixtures; (3) 50:50 tin-lead solder; and (4) excessive solder flux. Lead pipe was in use from the Roman times until World War II when lead became too expensive for that use (Walker and Oliphant 1982). Although galvanized pipe may contain approximately 0.1 percent lead, no direct link to lead in water has been observed (Lee, Becker, and Collins 1988). Most faucets are made of chrome-plated brass. The SDWA of 1986 required lead content of these fixtures to be held to less than 8 percent. It has been estimated that up to 33 percent of the USEPA first draw sample (125 ml following 6- to 8-hour stagnation time) may contain lead leached from the faucet. Furthermore, it is estimated that 20 faucet volumes of water must be passed before the faucet effect is eliminated (AWWA 1990). Galvanic effects due to contact with a given copper line is likely to contribute to plumbosolvency. Galvanic effects are the primary driver in lead dissolution from 50:50 tin-lead soldered joints. Figure 1 shows a copper tube with workmanship defects that can contribute to increased dissolution of lead as a result of turbulence generated at unreamed tube ends. One study (Lee, Becker, and Collins 1988) revealed that soldered copper pipes released as much lead as did lead pipe. An important contributor to plumbosolvency in all these cases is the use of water lines as electrical grounds. Under the correct circumstances, electric current has been found to drive the dissolution of lead. One site survey during the study detected a ground current of 7 amperes. It was noted that grounding currents in combination with 50:50 solder becomes a major source of lead in sites that were over 5 years old.

Common Mediation Approaches

The last line of defense against plumbosolvency is to replace any lead-containing pipes, solders, or fixtures. Many new SDWA compliant solders are on the market (Irving 1992). Faucets are manufactured almost universally of chrome-plated bronze. Substitutions may be hard to acquire locally, but they do exist (Lee, Becker, and Collins 1988).

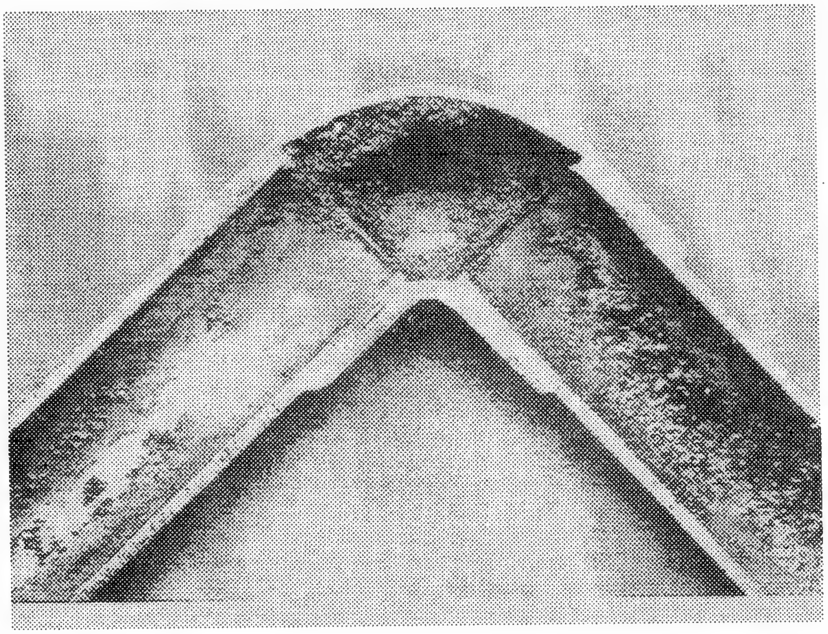

Figure 1. Copper tube showing workmanship defects, i.e., unreamed tube ends, solder globs, and excess solder flux

A widely applied approach involves the addition of corrosion inhibitors (USEPA 1992). Carefully controlled chemical feed systems apply complexing ligands that combine with dissolved lead to form passive films. The selection of chemicals used for this application generally comes from two families: phosphates and silicates.

Another well proven approach involves manipulation of the pH and alkalinity of the system water to develop a film of passive lead carbonates or basic lead carbonates (Boffardi 1993; USEPA 1992). This option often involves an increase in pH to reduce lead solvency as well as an increase in alkalinity to stabilize the pH. A chemical feed system is installed to administer appropriate dosages of CO_2, NaOH, CaO, $NaHCO_3$, or other applicable species. The systems require considerable maintenance and careful monitoring.

The application of a barrier film can be approached in two ways: (1) manipulation of water quality to force deposition of calcium carbonate, or (2) in-situ application of a thermoset epoxy coating.

Water Quality Manipulation

The manipulation of water quality is a well established approach. However, it can be difficult to execute. The solubility of calcium carbonate has been modeled via various indices that are a function of temperature, total hardness, alkalinity, and pH. Examples of these include the Langelier, Ryznar, and the Calcium Carbonate

Precipitation Potential indices. None of these indices provide accurate predictions in every case, yet when the right conditions are attained, a thin protective film can be deposited. Care must be taken to ensure that minimal hydraulic efficiency is lost in the process. Complicating this concern is that the film cannot be laid down evenly throughout the system since the calcium carbonate equilibrium changes continuously. Chemical feeds, controls, and monitoring are required here as well.

In-Situ Epoxy Coating

The latter approach (in-situ epoxy coating) is a relatively new development in the United States (American Pipe Lining 1988). The technology has existed for 30 years in the Pacific Rim. Introduced into the United States in the last 7 years, the process involves application of a 0.007-in. thick film of 100 percent solids epoxy resin (1 in. = 25.4 mm). After the initial "slug" of coating is passed through the pipe via air pressure, a high velocity air flow facilitates uniform spreading. The process costs up to 50 percent of system replacement, yet it is designed to last for 15 years, maintenance free. A lingering concern involves the difficulty in verifying the integrity of a coating in terms of a measurable defect frequency. The majority of these coating defects occur at joints, which are also the source of two-thirds of the lead.

3 Laboratory Evaluation of Corrosion Inhibitors Using Static Jar Tests

Laboratory Procedure

Small amounts of stock solutions (3.5 to 4.0 mL) of the three treatment options were added to 500 mL polyethylene bottles, each containing a lead/copper corrosion specimen and the appropriate test water. Sample bottles were filled as much as possible in an attempt to minimize potential pH drift. The water was changed twice daily and replaced with water of the same chemical makeup. The water was changed at 9:00 a.m. and 3:00 p.m.. The water from the 9:00 a.m. changing was discarded, and the water from the 3:00 p.m. changing was retained for analysis. This served to mimic the 6-hour standing sample mandated by the Lead and Copper Rule. Reagent grade laboratory chemicals were blended with deionized water to obtain the desired hardness, alkalinity, and total dissolved solids (TDS) concentrations. The solution pH was adjusted by bubbling a combination of 5 percent CO_2 in air, with compressed air, until the desired pH was reached. Oxygen concentrations remained constant for all of the carboys at 7.8-8.0 mg/L.

Stock Solution Preparation

The three chemical inhibitor treatments were first diluted to a stock solution, and then added to the 500 mL bottles. Water Treatment #2 (WT2) silicate stock solution was prepared by diluting 5.0 gm of PQ Corporation N® sodium silicate solution to 1 liter. The zinc phosphate stock solution (WT3) was prepared by dissolving 1.0 gm of Technical Products Corporation Virchem® 939 in 1 L of deionized water, and the blended ortho/polyphosphate (WT4) was prepared by dissolving 1.0 gm of Technical Products Corporation TPC® 532 into 1 L. Each 500 mL bottle using WT3 and WT4 had 3.5 mL of stock solution added, and the WT2 blend had 4.0 mL of stock solution added.

Preparation of Water Qualities

Each of the different water qualities was prepared using reagent grade chemicals and laboratory grade deionized water. The actual method for each is outlined below.

Water Quality #1 (WQ1). Stock hardness solution was prepared by dissolving 4.0 gm of $CaCl_2.H_2O$ and 3.65 gm of $MgCl_2.6H_2O$ in 2 L of deionized water. Researchers added 100 mL of this solution to the carboy along with 1.3 gm $NaHCO_3$ and 5.0 gm of NaCl, then the solution was diluted to 45 L final volume. The pH was adjusted to 7.0 by bubbling a mixture of CO_2 in air through the solution. The water was carbonated for an additional 2 minutes and then sealed to reduce pH drift. The resulting water quality was a pH of 7.0, a hardness of 5.0 mg/L, and 20 mg/L alkalinity.

Water Quality #2 (WQ2). Prepared the same as WQ1, except that 16.2 gm of $NaHCO_3$ was used to increase alkalinity. The resulting water quality was a pH of 7.0, a hardness of 5.0 mg/L, and 200 mg/L alkalinity.

Water Quality #3 (WQ3). Prepared the same as WQ1, except that the solution was not carbonated. The finished water quality was a pH of 8.0, a hardness of 5.0 mg/L, and 20 mg/L alkalinity.

Water Quality #4 (WQ4). Prepared the same as WQ2, except that the solution was not carbonated. The resulting water quality was a pH of 8.0, a hardness of 5.0 mg/L, and 200 mg/L alkalinity.

Water Quality #5 (WQ5). The water was prepared by dissolving 4.0 gm of $CaCl_2.2H_2O$, 3.65 gm of $MgCl_2.6H_2O$, and 1.3 gm of $NaHCO_3$ in 45 L of deionized water. The water was then carbonated with CO_2 mixed with air until the pH reached 7.0. Water Quality #5 had a pH of 7.0, a hardness of 100 mg/L, and 20 mg/L alkalinity.

Water Quality #6 (WQ6). This water was prepared the same as WQ5, except 16.2 gm of $NaHCO_3$ was used. The final water quality was pH 7.0, a hardness of 100 mg/L, and 200 mg/L alkalinity.

Water Quality #7 (WQ7). Prepared the same as WQ5, except no carbonation was used. The resulting water quality was a pH of 8.0, a hardness of 100 mg/L, and 20 mg/L alkalinity.

Water Quality #8 (WQ8). Same preparation as WQ6, except solution was carbonated to pH 8.0. The final water quality for WQ8 was a pH of 8.0, a hardness of 100 mg/L, and 200 mg/L.

Table 1 lists the various water qualities and treatments investigated in this study. The water quality parameters are all approximate, and in practice showed some slight variation. The pH values showed the most variance, but in all cases were within 0.2 pH units of the target pH in the carboys.

Table 1. Water quality/water treatment.

Water Quality	Water Treatment	Water Quality Parameters pH	Hardness (mg/L)	Alkalinity (mg/L)
WQ1, T1	Control	7.0	5	20
WQ1, T2	Silicate	7.0	5	20
WQ1, T3	Zinc phosphate	7.0	5	20
WQ1, T4	Ortho/poly PO_4	7.0	5	20
WQ2, T1	Control	7.0	5	200
WQ2, T2	Silicate	7.0	5	200
WQ2, T3	Zinc phosphate	7.0	5	200
WQ2, T4	Ortho/poly PO_4	7.0	5	200
WQ3, T1	Control	8.0	5	20
WQ3, T2	Silicate	8.0	5	20
WQ3, T3	Zinc phosphate	8.0	5	20
WQ3, T4	Ortho/poly PO_4	8.0	5	20
WQ4, T1	Control	8.0	5	200
WQ4, T2	Silicate	8.0	5	200
WQ4, T3	Zinc phosphate	8.0	5	200
WQ4, T4	Ortho/poly PO_4	8.0	5	200
WQ5, T1	Control	7.0	100	20
WQ5, T2	Silicate	7.0	100	20
WQ5, T3	Zinc phosphate	7.0	100	20
WQ5, T4	Ortho/poly PO_4	7.0	100	20
WQ6, T1	Control	7.0	100	200
WQ6, T2	Silicate	7.0	100	200
WQ6, T3	Zinc phosphate	7.0	100	200
WQ6, T4	Ortho/poly PO_4	7.0	100	200
WQ7, T1	Control	8.0	100	20
WQ7, T2	Silicate	8.0	100	20
WQ7, T3	Zinc phosphate	8.0	100	20
WQ7, T4	Ortho/poly PO_4	8.0	100	20
WQ8, T1	Control	8.0	100	200
WQ8, T2	Silicate	8.0	100	200
WQ8, T3	Zinc phosphate	8.0	100	200
WQ8, T4	Ortho/poly PO_4	8.0	100	200

Discussion of Results

Analytical Chemistry Data—Lead Solvency

The analytical data on the 6-hour standing samples is presented in the tables that follow. There were very high lead levels in virtually all the solution/treatment mixtures at the beginning of the study. The cylindrical copper corrosion specimens that were placed in each 500 mL bottle were painted on the exterior, and were coated with lead over a fixed percentage of the interior. These specimens were designed in this manner to generate as much lead as possible for the purpose of this study. There was a general downward trend in lead concentrations in most of the solutions, with the zinc phosphate treatment appearing to offer the best general solution for most

chemistry combinations. There was some variation evident in the pH of some solutions. Since this was not evident in the carboys, this variation was probably due to mixing with air when adding to the bottles and removing the specimen before analysis. The addition of the treatment solutions themselves obviously affected the solution pHs as well. The lead analysis showed occasional high spikes and some scatter of the data as is common for short-term lead studies. The analytical results are detailed in Appendix Tables A1 to A64.

WQ1. This water quality showed reasonable passivation of the lead for all four treatments, including the control. The control, silicate, and blended phosphate all provided roughly equal passivation with the lead concentration dropping to an average concentration of about 15 µg/L. The zinc orthophosphate dropped the lead concentration much lower, with values below the detection limit four of the last 8 days. This was clearly the most effective treatment for this water quality.

WQ2. This water quality showed that the silicate and blended phosphate treatments offered marginal improvement over the control. The zinc phosphate again appeared to offer noticeably superior inhibition over the other treatments in this water.

WQ3. This water quality showed virtually equal performance for the control, zinc phosphate, and blended phosphate. However, the silicate treatment performed very poorly with the average lead concentration remaining above 200 µg/L in the last week.

WQ4. The zinc phosphate treatment exhibited the best inhibition with this water quality. The silicate treatment performed almost as well, and both showed considerable improvement over the control. The blended phosphate showed very poorly with this water quality, with the average lead concentration only dropping to about 125 µg/L during the last week.

WQ5. The zinc phosphate blend was clearly the best treatment for this water quality. Interestingly, the control was much better than the silicate and blended phosphate for this water quality. The average lead concentrations for the last week of the study were approximately 23 µg/L for the control, 190 µg/L for silicate, 11 µg/L for the zinc phosphate, and 170 µg/L for the blended phosphate.

WQ6. The control and zinc phosphate showed comparable performance for this water quality with the blended phosphate and silicate again performing poorly.

WQ7. Once again, the control and zinc phosphate exhibited roughly comparable lead levels. The silicate treatment and blended phosphate both performed poorly with this water quality as well.

WQ8. The zinc phosphate treatment showed considerably lower lead levels when compared with the other treatments. The blended phosphate appeared to show some improvement over the control and silicate treatment.

Weight Loss Data

The corrosion specimens were weighed before and after the study to determine weight loss. Since there were two metals of distinctly different densities, weight loss rate calculations could not be done. Metal concentration data in this type of study does not always correlate well with weight loss data, and that was true for this case. The blended phosphate specimen showed the least weight loss for WQ1, WQ2, WQ4, and WQ6. The zinc phosphate specimen exhibited the least weight loss for WQ3, WQ5, WQ8, and was essentially equal to the control for WQ7. Control specimens had the highest weight loss for all four water qualities with an alkalinity of 200 mg/L, and the silicate specimens had the highest weight loss for all water qualities with an alkalinity of 20 mg/L. The short duration of this study makes weight loss data of questionable value. The cleaning blank exceeded weight loss for many of the specimens. Corrosion specimen weight loss data is presented in Table 2.

Secondary Impacts

There was little attempt made to access secondary impacts of the treatments tested in this study on the water quality due to the obvious limitations of a jar test study. Researchers did, however, monitor the turbidity. This could impact the water quality both aesthetically and, more importantly, by negatively impacting the disinfection efficiency. Current Federal Regulations set turbidity limits at 0.5-1.0 nephelometric turbidity units (ntu), depending on system size, etc. While most water qualities initially were somewhat high, only six combinations of water quality and treatment exceeded the 0.5 limit by the end of the study. Most of the test waters that did exceed were only marginally above the low standard. Water Quality #3 had two high turbidity combinations; the silicate treatment was 1.1 ntu and the zinc orthophosphate was 0.6 ntu on the final day of the study. Water Quality #6 also had two somewhat high turbidity combinations; the zinc orthophosphate was 0.6 ntu and the blended phosphate was 0.8 ntu on the final day of the study. The only two markedly high turbidity solutions were both controls, those being Water Qualities #4 (1.8 ntu) and #6 (2.0 ntu).

Table 2. Weight loss data.

Water Quality Treatment	Specimen ID #	Copper/Lead Insert		
		Weight, i	Weight, f	Weight Loss*
WQ1, T1	G000861CB	63.9808	63.9452	0.0154
WQ1, T2	G000883CB	63.5581	63.5002	0.0377
WQ1, T3	G000803CB	63.1746	63.1342	0.0202
WQ1, T4	G000811CB	63.5704	63.5439	0.0063
WQ2, T1	G000812CB	66.6955	66.6335	0.0418
WQ2, T2	G000831CB	63.4893	63.4428	0.0263
WQ2, T3	G000801CB	63.7784	63.7307	0.0275
WQ2, T4	G000892CB	63.6544	63.6128	0.0214
WQ3, T1	GC00840CB	63.5871	63.5468	0.0201
WQ3, T2	G000846CB	64.6818	64.6111	0.0505
WQ3, T3	G000849CB	64.5634	64.5302	0.013
WQ3, T4	G000860CB	63.9855	63.9437	0.0216
WQ4, T1	G000895CB	64.6963	64.5878	0.0883
WQ4, T2	G000884CB	63.7134	63.6787	0.0145
WQ4, T3	G000819CB	64.0416	64.0154	0.006
WQ4, T4	G000809CB	64.3157	64.2916	0.0039
WQ5, T1	G000807CB	63.565	63.5133	0.0315
WQ5, T2	G000847CB	64.0554	63.9921	0.0431
WQ5, T3	G000875CB	63.9222	63.8865	0.0155
WQ5, T4	G000896CB	64.5984	64.5546	0.0236
WQ6, T1	G000933CB	63.9925	63.9405	0.0318
WQ6, T2	G000915CB	63.6928	63.6427	0.0299
WQ6, T3	G000943	66.3814	66.3304	0.0308
WQ6, T4	G000806CB	64.3787	64.3328	0.0257
WQ7, T1	G000955CB	66.2721	66.2424	0.0095
WQ7, T2	G000859CB	64.1155	64.0561	0.0392
WQ7, T3	G000951CB	66.6088	66.5787	0.0099
WQ7, T4	G000826CB	64.1567	64.1153	0.0212
WQ8, T1	G000870CB	64.9024	64.7953	0.0869
WQ8, T2	G000905CB	63.4193	63.3753	0.0238
WQ8, T3	G000813CB	63.6251	63.5948	0.0101
WQ8, T4	G000878CB	64.4179	64.3682	0.0295

* Weight loss = W_i - (W_f + cleaning blank of 0.02 g)

Wilcoxon Signed Rank Test

The Wilcoxon Signed Rank Test (Wilcoxon), a statistical evaluation recommended in the LCR guidance manual (USEPA 1992), as well as by the USEPA (AWWA 1992), is a nonparametric statistical analysis applied to paired replicate data where two data sets represent pre- and post-treatment observations (Kirk 1990). The Wilcoxon is based on the rank of the absolute difference between paired observations rather than on the numerical value of the difference.

For the purposes of reviewing and analyzing dissolved lead data, paired data were examined among four water treatment conditions (control, silicate, zinc phosphate, and blended ortho/polyphosphate) under eight water quality conditions. The Wilcoxon statistical method was applied to test for significant differences between treatments since the source water for each group of four treatments in a group was the same. The Wilcoxon measure the effect of treatment strategies employed in modeling since most other factors were controlled under experimental conditions.

The Wilcoxon signed rank tests (Appendix B) provide statistical data for lead concentrations versus water treatments within a water quality group. Data for lead from each group is presented in graphical form followed by the Wilcoxon data for lead from that group. For the purposes of this study, water quality (WQ) is the group designation and water treatment (WT) is the parameter modified within each group to impact lead concentration. The Wilcoxon tables consist of three sections:

1. *Counts of differences*: This section presents the number of times lead values from a given WQ and WT, listed along the left-hand side, are greater than the lead values from one of the other WTs listed along the top of this section.
2. *Z*: "Z" represents the tabulated statistics obtained by dividing the sum of the signed ranks by the square root of the sum of the squared ranks. The Z statistic is given meaning by the probability value obtained in statistical tables.
3. *Two-Sided Probabilities*: This final section provides the statistical significance to the corresponding Z-value in the middle section. In general, a probability of 1.0000 means the paired rankings are indistinguishable from one another in terms of preferability and the differences between them are insignificant. A probability of 0.0001 equals a 99.99 percent probability the samples obtained are significantly different and distinguishable.

If all conditions are accounted for and controlled, such as using the same source water and controlling conditions for the water treatment parameters within a group, etc., then the Wilcoxon analysis should reflect the impact of the different water treatment strategies for controlling lead for that water quality.

Water Quality #1 (WQ1)

Overall, WT3 showed the greatest number of lower lead counts over the test period under this WQ condition. The significance in all cases was greater than 99 percent. WT4 ranked second in lowest lead concentrations, but was less significant. WTs 1 and 2 were approximately equal with the overall effectiveness being indeterminable.

Water Quality #2 (WQ2)

Overall, there was no significantly better water treatment under this water quality condition. Based on the Wilcoxon, WT2, WT3, and WT4 were indistinguishable in terms of lower lead concentration. However, all water treatments proved lower that the control (WT1) with a significance greater than 99.7 percent.

Water Quality #3 (WQ3)

In general, WT3 lead values were lower than in the other water treatment alternatives. However, the control lead values showed an equal distribution making WT3 statistically similar to WT1. WT4 lead values were generally lower than WT2 values.

Water Quality #4 (WQ4)

WT3 showed a substantially greater number of lower lead value counts than all other water treatments under this water quality condition with a significance of greater than 99.9 percent. WT2 was indistinguishable from WT1 and WT4.

Water Quality #5 (WQ5)

WT3 showed a substantially greater number if lower lead values than all other water treatments under this water quality condition with a significance of greater than 99.6 percent. Slightly more WT1 lead values were lower than WT2 and WT4. WT2 and WT4 were virtually indistinguishable.

Water Quality #6 (WQ6)

In general, WT3 lead values were lower than in the other water treatment alternatives. However, the control lead values showed a nearly equal distribution of higher and lower concentrations making WT3 statistically similar to WT1. WT2 and WT4 lead concentration distributions were statistically indistinguishable.

Water Quality #7 (WQ7)

In general, WT3 lead values were lower than in the other water treatment alternatives. However, the control lead values showed a nearly equal distribution of higher and lower concentrations making WT3 statistically similar to WT1. WT2 and WT4 lead concentration distributions were statistically indistinguishable.

Water Quality #8 (WQ8)

WT3 lead concentrations were more often lower than in all other water treatments under this water quality condition (significance greater than 99.9 percent). WT1 and WT2 were indistinguishable from WT4.

In general, WT3 (zinc phosphate) showed lower lead counts in greater numbers when compared among the three water treatments and the control. In some instances, WT1 (the control) was statistically indistinguishable from WT3 (under WQs 6 and 7). Table 3 summarizes the results.

Table 3. Wilcoxon signed rank test results.

Water Quality	Water Treatment Rank			
WQ1	T3	T4	T2, T1	--
WQ2	T2, T3, T4	T1	--	--
WQ3	T3	T1	T4	T2
WQ4	T3	T1, T2, T4	--	--
WQ5	T3	T1	T2, T4	--
WQ6	T1, T3	T2, T4	--	--
WQ7	T1, T3	T2, T4	--	--
WQ8	T3	T1, T2, T4	--	--

4 Laboratory Evaluation of In-Situ Pipe Coating

Blow-Through Coating Application

For use inside of building facilities, a given rehabilitation technique must involve equipment that can negotiate doors and entrances as well as methods that minimize the number of pipe joints that would need to be accessed. Several rehabilitation technologies are currently available including: slip-lining, grout applications, spray-on liners, felt sock liners, dual pig coating, and blow-through coating (Pipe Line Industry 1987; Blakey 1985; Tyrpak 1987; Ouelette and Shrock 1981; *Public Works* 1975; Shrock 1985; Rix 1985; Utz 1983; Dann 1974; Nakamora 1993). Each of these technologies has been successfully applied to straight run systems with diameters larger than 2 in.

The specimen used for the blow-through application consisted of two 6-in. sections of 1-1/8-in. diameter copper pipe soldered to each end of a 90-degree elbow (Figure 2). The specimen was then abrasively blasted with silica sand at a pressure of approximately 100 psi (1 psi = 6.89 kPa) giving the inner pipe surface a 2- to 3-mil profile. It was then attached to the coating application loop (Figure 3) via a flexible coupling.

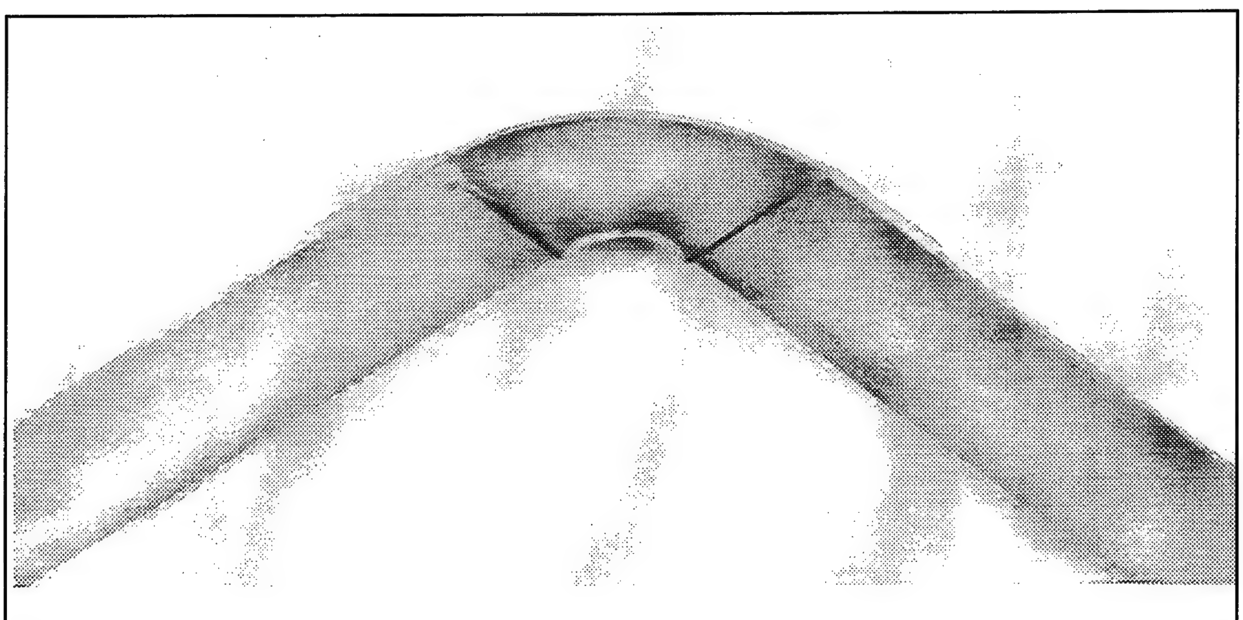

Figure 2. Sectioned copper pipe specimen used in blow-through coating application tests.

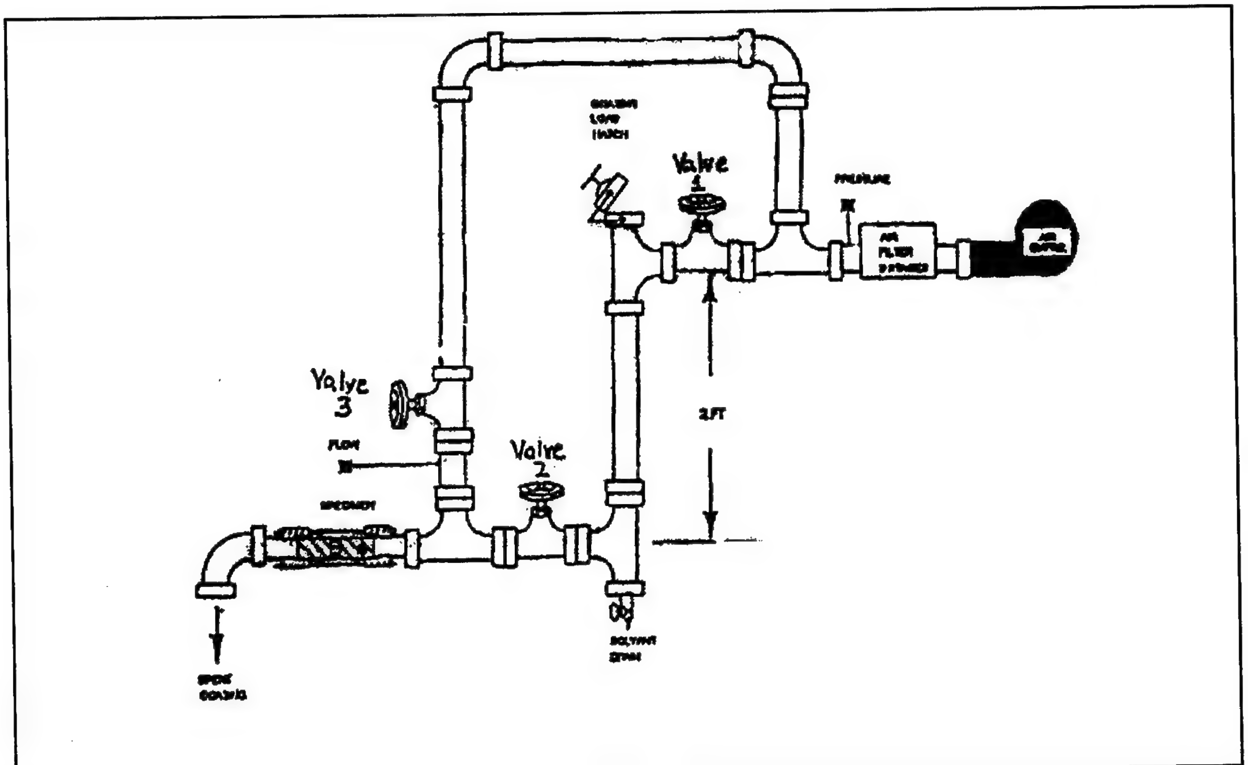

Figure 3. In-situ coating application loop.

Fifty to sixty milliliters of coating was prepared by mixing the base component and the curing agent in a 1:1 ratio and delivered to the application loop through the coating load hatch with all valves closed. The hatch was closed and valve 1 (Figure 3) was opened in conjunction with the air being turned on at a pressure of approximately 30 psi. Valve 2 was then opened quickly, allowing the coating to enter the pipe specimen. The coating residue was collected in a drainage pan beneath the specimen. At this time, valves 1 and 2 were closed and valve 3 was opened, allowing air to pass through the specimen for the duration of the curing process.

Cleaning the pipe loop between the coating load hatch and the solvent drain (which held the coating prior to application) was done immediately. The load hatch and the solvent drain were opened and the section was flushed with xylene until the effluent ran clear. This took approximately 100 ml of xylene.

By visual inspection, it was observed that coverage was not complete. Therefore, a second coat was applied using the same procedure described above. Air was allowed to pass through the specimen overnight (approximately 16 hours). Borescope inspection revealed that the inside of the elbow and the end of the specimen were unevenly coated. A third coat was applied using the procedure described previously. Air was applied overnight (approximately 26 hours) and the specimen was observed to be completely coated.

In-Situ Device Coating Application

The specimen used for the in-situ device application was a 1-ft section of 1-1/2-in. diameter acrylic pipe. The specimen was abrasively blasted with silica sand at a pressure of 100 psi, giving the inner pipe surface a 2- to 3-mil profile. The specimen was attached to the coating application loop via a flexible coupling, flexible hose, and a hose bib. The hose bib forms a tight seal with the walls of the pipe. Prior to the coating application, air pressure tests were conducted to determine how much pressure was needed to push the device through the pipe. Once this was determined, the epoxy coating was mixed as described in the blow-through coating application procedure. The device (Figure 4) was placed in the pipe and about 60 ml of the coating was injected into the device. The pipe was re-attached to the application loop and air pressure applied at approximately 30 psi. At the required pressure, the device moved through the pipe, coating the pipe as it passed through. The result was a thin uniform coating free of pooling over the entire inner wall of the pipe. Ambient air flowed through the pipe overnight to cure the coating. Several holidays (streaks and circular areas) were observed through the circumference.

Discussion of Experimental Results

The blow-through technique required a number of coating applications to ensure that the inside surface of the pipe was coated. The coating thickness measured at various locations on the specimen is summarized in Table 4 and the locations are shown in Figure 5. The data shows nonuniformity in the applied coating thickness with a minimum of 0.005 in. at Location 6 to a maximum of 0.115 in. at Location 5. Pooling

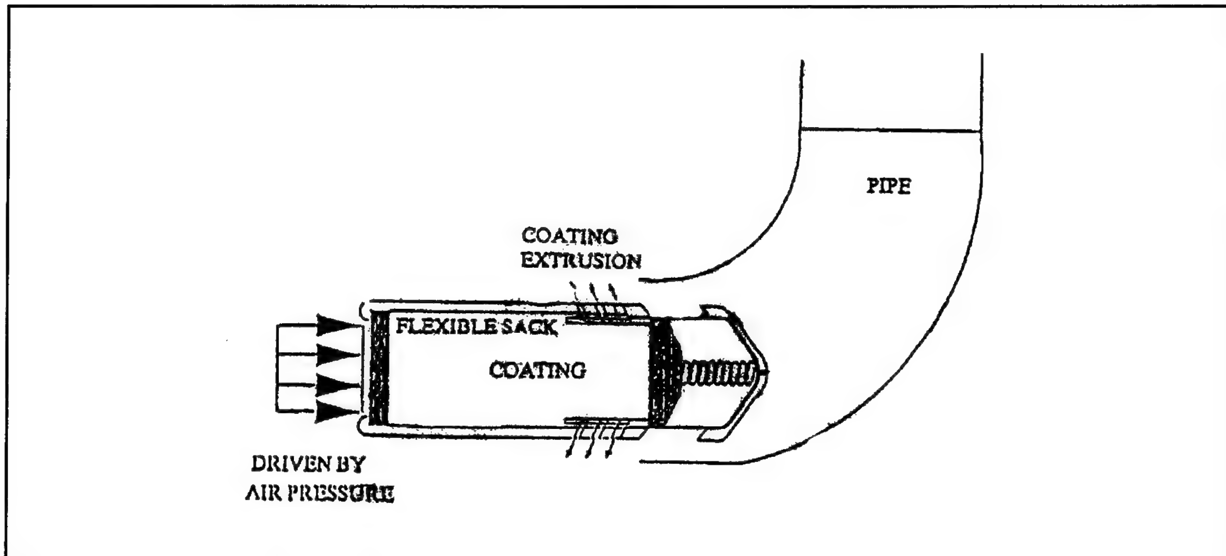

Figure 4. In-situ coating application device.

Table 4. Coating thickness measurements.

Location	Thickness (in.)
1	0.006
2	0.011
3	0.016
4	0.097
5	0.115
6	0.005

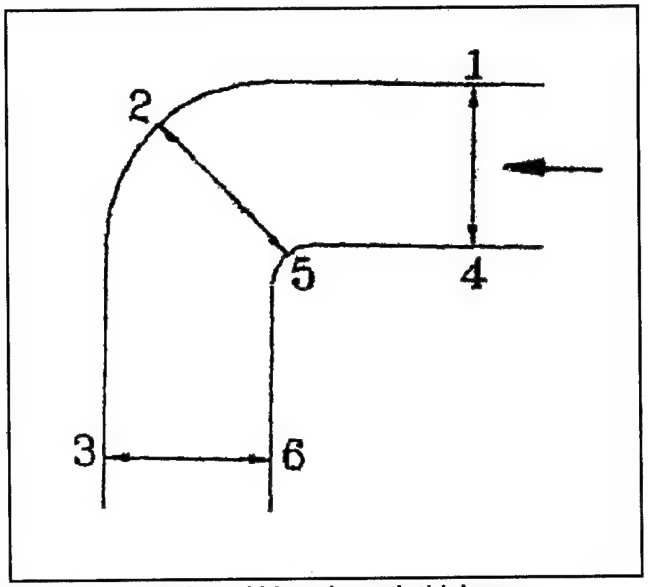

Figure 5. Location of blow-through thickness measurements.

resulted along the bottom of the horizontal section of the specimen and several thin areas and bubbling (trapped air) occurred along the top of the horizontal section of specimen and the throughout the vertical section. A minimum thickness of 7 mil (0.007 in.) is recommended for in-situ coating thickness; these results demonstrate that this minimum thickness is not present throughout the entire specimen. In addition, the pooling reduces the pipe capacity, which is detrimental to the system operation.

The preliminary laboratory data indicate that uniformity of coating deposition along the entire length of a small diameter (less than 2 in.) plumbing system will be difficult to achieve. As expected, it was difficult to achieve a uniform coating on the inside surfaces of the elbow.

Holidays observed throughout the interior of the device coated specimen were associated with two sources. Streaks were attributed to the irregular circumferential profile of the trailing piece of the device. Refinement of the trailing end profile is expected to alleviate this problem. Circular holidays were attributed to pockets of air that developed during passage of the device. It is anticipated that increasing the sack length of the device will permit the delivery of a greater flow volume of coating, which will increase the thickness of the deposited film and thus mitigate the impact of entrapped air. Increasing extrusion pressure between the nose cone and the end piece of the device should also enhance the development of a holiday free film. The addition of a trailing trowel should assist in eliminating the development of all types of holidays.

5 Field Testing

Preliminary Analysis of Site Water Quality

A preliminary analysis of the site water treatment plant and distribution system water quality was performed. A 12-month summary (February 1993 through January 1994) of water treatment plant logs including water quality parameters from the Little Patuxent River (surface water) and Patuxent Aquifer (well water) supplies, as well as treatment chemicals, and pump logs were reviewed.

Table 5 summarizes relevant water conditions at the site. It was determined that the average blend of surface water and well water for the period February 1993 through January 1994 was approximately 85 percent surface water and 15 percent well water. The average principal water quality parameters for the raw surface supply were: (1) pH, approximately 7.4; (2) alkalinity (as $CaCO_3$), approximately 50 mg/L; and (3) calcium hardness, approximately 63 mg/L. The average principal water quality parameters for the raw well supply for the same period were: (1) pH, approximately 4.8; (2) alkalinity (as $CaCO_3$), approximately 9 mg/L; and (3) calcium hardness, approximately 6 mg/L. The average principal water quality parameters for the blended tap water were: (1) pH, 7.5 to 7.7; (2) alkalinity (as $CaCO_3$), 50 to 75 mg/L; and (3) calcium hardness, approximately 60 to 80 mg/L. During this period, there were 8 days on which the source was 100 percent well water. However, the average blended tap water quality parameters were critical factors in determining the corrosion control treatments used in the pipe-loop models.

Table 5. Water conditions at Fort Meade.

Parameter	River Water	Well Water	Blended Tap Water
pH	7.4	4.8	7.5-7.7
Alkalinity	50 mg/L	9 mg/L	50-75 mg/L
Calcium Hardness	63 mg/L	6 mg/L	60-80 mg/L

Field Test Approach

The efficacy of a specific corrosion control program is best shown by demonstration of strategies in pipe-loop models. Since the Lead and Copper Rule (LCR) specifies that 1-liter water samples are to be collected from kitchen taps, pipe-loop models were constructed to closely mimic typical household plumbing. Further, nonmetallic (i.e., plastic) fittings and pipe material were used throughout the models to minimize extraneous sources of metal contamination.

Twelve pipe loop models were constructed according to U.S. Army Construction Engineering Research Laboratory (ASTM/CERL) protocol (AWWA 1990). Figure 6 shows the pipe loop model assembly drawing, including the programmable solenoid modification.

All samples were collected 1 day per week (usually on Wednesdays) in high density polyethylene (HDPE) containers and preserved according to method specific protocols. Lead, copper, zinc, and iron samples were analyzed by an independent, Maryland State-certified laboratory according to the appropriate method. Each sample was collected from the exit portal located just prior to a programmable solenoid on the independent racks.

Standing samples were collected after an 8-hour static period (i.e., after 9:30 a.m.) once each week. All water quality parameters were analyzed according to USEPA-specified methods by an independent, Maryland state-certified laboratory except for temperature, free chlorine, pH, total dissolved solids/conductivity, and turbidity. These parameters were analyzed according to USEPA methods but conducted immediately on site. Dissolved oxygen, alkalinity, and phosphate were analyzed in tandem with the independent laboratory to assist in adjusting pipe loop chemistry in the absence of immediate independent laboratory sample results.

Field Test Procedures

The pipe loop models were operated continuously for a period of 90 days, beginning immediately after completion of the flushing period (25 May 1994). Additional monitoring, to maintain dosages and fluids in the systems, was done as needed throughout the study period.

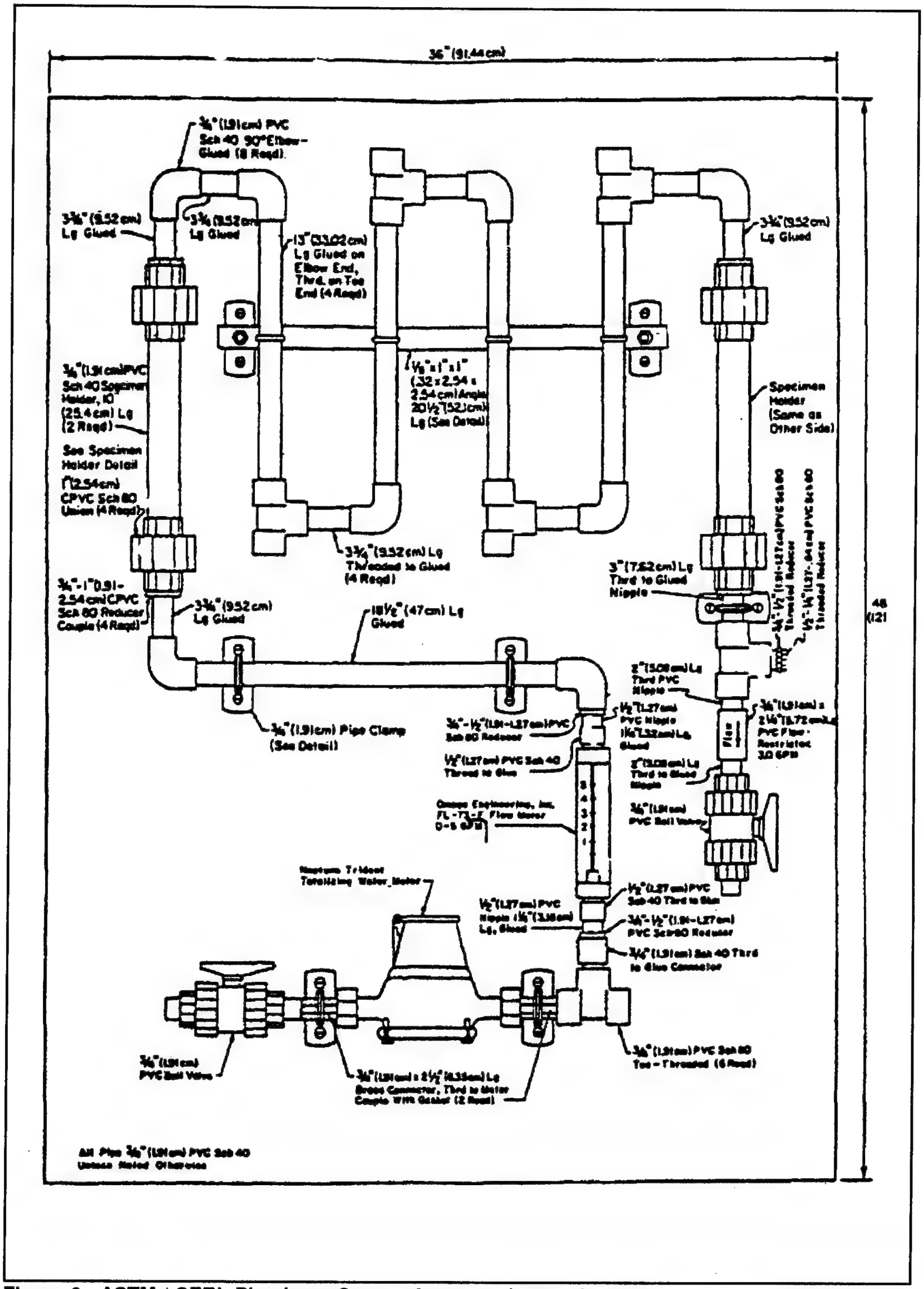

Figure 6. ASTM / CERL Pipe Loop System for corrosion testing.

Field Test Results

Figure 7 shows the results of the 90-day pipe loop tests for lead. The pH/alkalinity adjustment data exhibited the widest scatter especially near the end of the test period. Each of the treatments exhibited lead values that exceeded the maximum contaminant level of 15 ppb (0.015 mg/L) at some time during the test period. Figure 8 shows the results of the pipe loop tests for copper. Almost all the copper levels observed were below the MCL of 1300 ppb (1.3 mg/L).

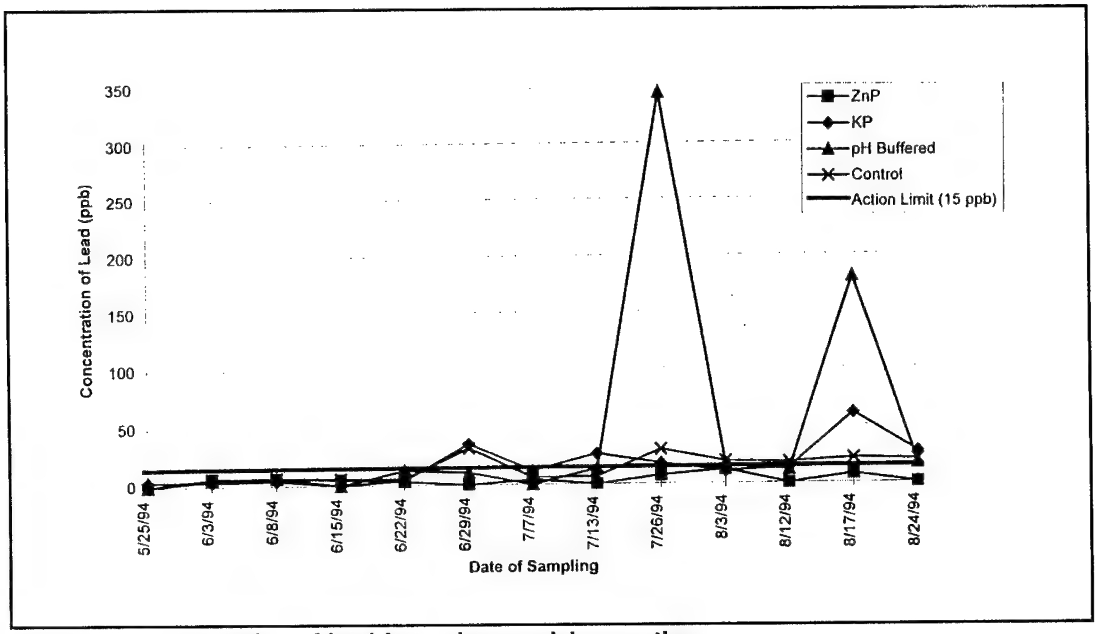

Figure 7. Concentration of lead from plant models over time.

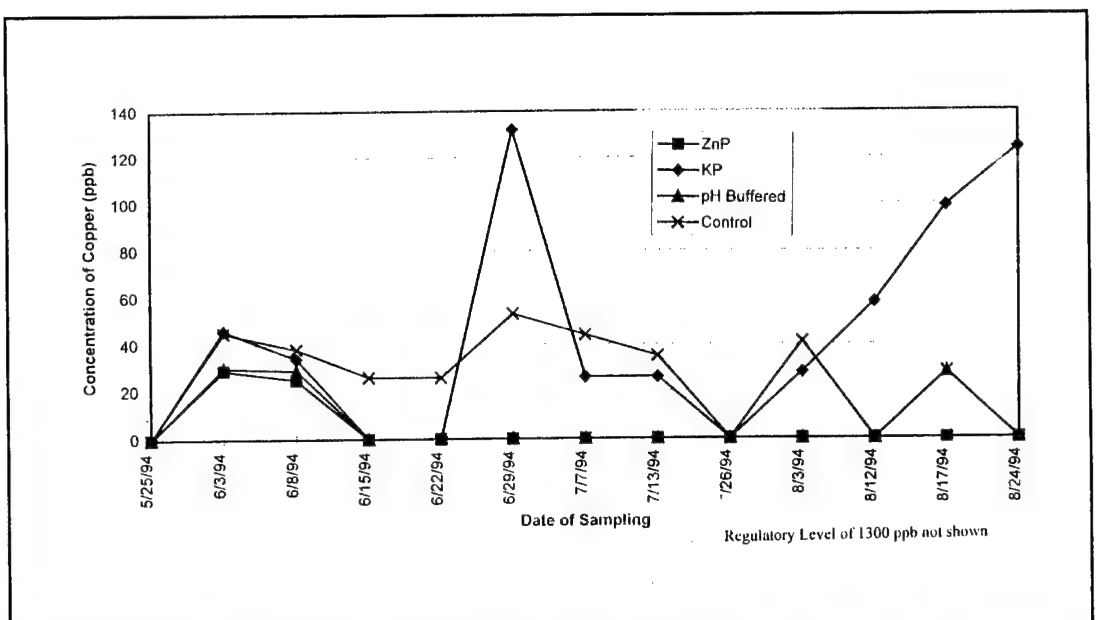

Figure 8. Concentration of copper from plant models over time.

The abbreviations ZnP, KP, and pH are used throughout this report to represent zinc orthophosphate/zinc potassium polyphosphate blended, monopotassium phosphate/potassium tripolyphosphate blended, and calcium hardness adjustment through pH and alkalinity modification, respectively. Table 6 lists a Wilcoxon rankings for the performance of the various treatments in controlling lead, copper and iron.

Table 7 is a decision matrix developed according with USEPA-recommended practice to evaluate public water system submittals for optimal corrosion control treatment recommendations. This table contains the decisionmaking worksheet for optimum corrosion control for the water supply with factors and weights used to generate the recommendation. (The weights and factors are listed in Table 8.)

Table 6. Summary rankings of corrosion control methods.

		Lead			Copper			Iron		
	Model	Mean*	Wilcoxon	Corrosion Rate	Mean	Wilcoxon	Corrosion Rate	Mean	Wilcoxon	Corrosion Rate
Plant	ZnP	1	1	1	1	1	1	2	3	4
	KP	3	4	2	4	4	3	4	4	2
	pH	4	3	4	2	2	2	1	1	1
	Control	2	2	3	3	3	4	3	2	3
Barracks	ZnP	1	1	2	1	1	2	2	2	4
	KP	2	2	1	2	2	1	1	1	1
	pH	4	4	3	4	4	3	4	4	3
	Control	3	3	4	3	3	4	3	3	2

*Note: 1 = best, 4 = worst

Table 7. Corrosion control water treatment decision matrix.

Metal	Score Weight	Zinc Phosphate	Potassium Phosphate	pH Adjusted	Control
Lead	85%	6	4	1	3
Copper	15%	5	5	5	3
Sub-Score	55%	3.22	2.28	1.60	1.65
Reliability	10%	6	5	2	4
Secondary Impacts	15%	3	3	3	2
Waste Water Impacts	15%	3	3	6	7
Costs	5%	5	1	4	3
Total Score	**100%**	**4.97**	**3.73**	**3.35**	**3.55**

Table 8. Wilcoxon weights and factors for corrosion control treatment recommendations.

Ranking	
Best	= 7
Better	= 4
Worst	= 0
Weighing Factors to Reflect Site Priorities	
Metal Reduction Performance	= 55 %
Reliability/Operability	= 10 %
Secondary Water Quality Impacts	= 15 %
Waste Water Treatment Impacts	= 15 %
Costs	= 5 %
Metal Reduction Performance Factors	
Lead	= 85 %
Copper	= 15 %

As listed in Table 7, the ZnP treatment ranked highest in weighted rank with a score of 4.97. This value was followed distantly with scores 3.73, 3.55, and 3.35 for the monopotassium orthophosphate/potassium tripolyphosphate, control, and pH/-alkalinity adjustment treatments respectively.

Individual rankings were based on the outcome of the experimental portion of this study. Specifically, the Wilcoxon statistics and corrosion rates, as well as some general statistics and toxicological considerations, provided the basis for ranking the individual strategies. Since zinc potassium polyphosphate/zinc orthophosphate performed better than the monopotassium orthophosphate/potassium tripolyphosphate, pH adjusted, and control models at the plant and barracks, this strategy ranked highest in this category.

6 Conclusions and Recommendations

Conclusions

Chemical Treatment

Great caution must be exercised in applying the results of a static jar test to full-scale implementation in an actual water distribution system. There are many variables that this type of study could not attempt to address. In general, WT3 (zinc phosphate) showed lower lead counts in greater numbers when compared among the three water treatments and the control. In some instances, WT1 (the control) was significantly indistinguishable from WT3 (under WQs 6 and 7).

The field test results showed that zinc orthophosphate is the preferred corrosion inhibitor for use in control of lead solvency in building plumbing when it is feasible to dose it at the water treatment plant. However, a zinc potassium polyphosphate/zinc orthophosphate blend (ZnP), maintained at a constant residual dosage of 3.0 to 5.0 mg/L as orthophosphate, operating under a pH of approximately 7.6 ± 0.2 pH units and alkalinity of approximately 70 mg/L (as $CaCO_3$) was demonstrated to be an effective corrosion control treatment strategy with regard to lowering lead and copper levels in pipe loop models located at the water treatment plant and in a barracks near the end of the distribution system in an actual site environment. In the field, the ZnP treatment also ranked highest in weighted rank over the monopotassium orthophosphate/potassium tripolyphosphate, control, and pH/-alkalinity adjustment treatments, respectively. The performance of the ZnP treatment, which was equal to or better than any of the other treatments in both the laboratory and field tests, is an excellent indication that it is a potentially viable treatment for lead corrosion inhibition under a variety of water qualities.

Blow-Through and In-Situ Coating

The blow-through coating application technique could require multiple coats for effective coverage—especially for locations such as bends and tees (Chapter 4). This process appears to work well on straight sections, but differences in applied coating thickness tend to occur between horizontal and vertical runs of pipe.

The in-situ pipe coating device appeared to apply a more uniform coating (free from pooling) than was achieved with the blow-through application process, independent of pipe configuration and material. Future modifications to the device will mitigate the development of holidays.

Recommendations

Chemical Treatment

Guidance for the selection of a given chemical treatment option for control of lead in building plumbing (PWTB 420-46-07, included as Appendix C to this report) should be implemented Army wide. This guidance is based on both laboratory and actual field tests of corrosion inhibitors for use in building plumbing systems.

Blow-Through and In-Situ Coating

Future work on blow-through application of coatings should focus on long-term durability and leachability as well as on the analysis of the modes of failure of candidate coatings. Also, further work should examine the feasibility of recoating.

It is recommended that a life cycle cost analysis be conducted for the nonchemical, in-situ coating technology for control of lead in building plumbing supplies. Further studies of in-situ coating must focus on application to fixtures, tees, and elbows as well as on the effects of changes in pipe size on coating efficiency.

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Appendix A: Analytical Data From Static Jar Tests

Table A1. Water Quality 1, Water Treatment 1, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	216	355	258	275	256	61	68	62	53	54
Copper (mg/L)	0.00	0.00	0.01	0.00	0.00	—	0.00	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	240	163	151	161	165	—	165	—	136	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	19	22	19	18	21	—	23	—	18	—
Hardness (mg/L as $CaCO_3$)	10	9	5	5	5	—	4	—	4	—
pH	7.14	6.90	7.13	7.77	7.83	—	7.13	—	6.95	—
Conductivity (μS/cm)	231	239	250	241	239	—	233	—	240	—
Temperature (°C)	20.2	21.1	23.3	21.4	21.4	—	19.7	—	21.0	—
Turbidity (ntu)	1.0	0.9	0.4	0.7	0.7	—	0.1	—	0.06	—

Table A2. Water Quality 1, Water Treatment 2, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	457	231	341	165	263	43	44	24	26	41
Copper (mg/L)	0.00	0.00	0.00	0.01	0.00	—	0.00	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	258	187	129	168	178	—	165	—	144	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	12.91	10.73	10.92	11.00	10.67	—	10.90	—	10.44	—
M Alkalinity (mg/L as $CaCO_3$)	24	24	23	22	22	—	22	—	21	—
Hardness (mg/L as $CaCO_3$)	7	5	5	4	4	—	4	—	4	—
pH	8.36	7.90	8.10	8.55	8.51	—	8.69	—	8.67	—
Conductivity (μS/cm)	242	245	257	246	244	—	237	—	245	—
Temperature (°C)	20.2	20.8	22.9	21.1	21.1	—	19.2	—	20.8	—
Turbidity (ntu)	18.0	10.0	15.0	3.0	1.4	—	0.08	—	0.08	—

Table A3. Water Quality 1, Water Treatment 3, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	801	89	152	140	58	22	23	5	13	15
Copper (mg/L)	0.00	0.00	0.01	0.02	0.00	—	0.03	—	0.02	—
Zinc (mg/L)	0.37	0.40	0.40	0.46	0.42	—	0.41	—	0.44	—
Total Dissolved Solids (mg/L)	161	165	117	144	166	—	152	—	145	—
Orthophosphate (mg/L as PO_4)	2.27	1.64	1.64	2.16	1.74	—	1.69	—	1.74	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	23	19	19	21	21	—	22	—	21	—
Hardness (mg/L as $CaCO_3$)	5	5	5	5	5	—	4	—	5	—
pH	7.13	6.91	6.98	7.05	7.13	—	7.08	—	6.81	—
Conductivity (μS/cm)	234	238	248	240	236	—	231	—	236	—
Temperature (°C)	20.1	20.7	22.7	21.1	20.8	—	19.2	—	20.7	—
Turbidity (ntu)	25.0	3.0	2.2	2.7	1.0	—	0.15	—	0.2	—

Table A4. Water Quality 1, Water Treatment 4, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	551	148	155	151	164	96	48	34	22	33
Copper (mg/L)	0.00	0.01	0.01	0.00	0.00	—	0.00	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	166	164	118	143	161	—	145	—	137	—
Orthophosphate (mg/L as PO_4)	1.50	1.20	1.21	1.21	1.57	—	1.13	—	1.35	—
Polyphosphate (mg/L as PO_4)	0.7	1.17	1.11	1.1	0.72	—	1.08	—	0.86	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	24	20	18	20	20	—	20	—	21	—
Hardness (mg/L as $CaCO_3$)	6	8	4	4	5	—	4	—	5	—
pH	7.08	7.02	7.05	7.07	7.03	—	7.03	—	7.13	—
Conductivity (μS/cm)	236	239	247	238	238	—	230	—	236	—
Temperature (°C)	20.4	20.9	22.7	21.1	20.9	—	19.3	—	20.6	—
Turbidity (ntu)	1.0	0.1	0.3	0.07	0.1	—	0.07	—	0.15	—

Table A5. Water Quality 2, Water Treatment 1, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	783	374	74	110	727	72	55	76	41	40
Copper (mg/L)	0.00	0.00	0.00	0.00	0.00	—	0.06	—	0.04	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	382	381	318	343	370	—	347	—	354	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	210	202	201	202	201	—	200	—	200	—
Hardness (mg/L as $CaCO_3$)	9	7	4	5	4	—	4	—	4	—
pH	7.20	7.10	7.18	7.26	7.26	—	7.32	—	7.29	—
Conductivity (μS/cm)	522	533	559	536	533	—	515	—	532	—
Temperature (°C)	20.3	20.8	22.8	21.1	21.0	—	19.3	—	20.6	—
Turbidity (ntu)	7.5	9.0	6.0	9.0	9.0	—	0.6	—	0.6	—

Table A6. Water Quality 2, Water Treatment 2, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	710	265	102	24	67	41	24	21	27	26
Copper (mg/L)	0.00	0.01	0.01	0.12	0.07	—	0.12	—	0.10	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	406	383	331	376	395	—	366	—	372	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	8.90	8.95	8.59	10.38	10.16	—	10.42	—	10.82	—
M Alkalinity (mg/L as $CaCO_3$)	213	201	200	203	202	—	203	—	202	—
Hardness (mg/L as $CaCO_3$)	5	7	5	5	4	—	4	—	5	—
pH	7.28	7.14	7.28	7.27	7.34	—	7.45	—	7.36	—
Conductivity (μS/cm)	533	540	561	540	533	—	520	—	536	—
Temperature (°C)	20.4	20.8	22.7	20.9	21.0	—	19.2	—	20.8	—
Turbidity (ntu)	14	8.0	10.0	0.3	0.6	—	0.09	—	0.12	—

Table A7. Water Quality 2, Water Treatment 3, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	744	396	141	24	37	24	21	15	12	16
Copper (mg/L)	0.00	0.01	0.02	0.01	0.00	—	0.06	—	0.03	—
Zinc (mg/L)	0.41	0.40	0.65	0.42	0.47	—	0.49	—	0.44	—
Total Dissolved Solids (mg/L)	389	375	334	348	369	—	348	—	338	—
Orthophosphate (mg/L as PO_4)	1.59	1.72	1.70	1.79	1.71	—	1.71	—	1.67	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	209	203	200	200	201	—	202	—	201	—
Hardness (mg/L as $CaCO_3$)	5	8	4	5	4	—	4	—	4	—
pH	7.16	7.11	7.18	7.23	7.26	—	7.33	—	7.25	—
Conductivity (μS/cm)	531	534	555	535	533	—	515	—	531	—
Temperature (°C)	20.4	20.8	22.6	21.1	20.9	—	19.4	—	20.8	—
Turbidity (ntu)	10.1	7.1	6.0	3.0	0.2	—	0.12	—	0.08	—

Table A8. Water Quality 2, Water Treatment 4, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	399	162	33	25	18	35	26	28	15	29
Copper (mg/L)	0.01	0.13	0.13	0.12	0.13	—	0.11	—	0.08	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	420	415	325	345	366	—	378	—	351	—
Orthophosphate (mg/L as PO_4)	0.84	0.80	0.80	0.63	0.73	—	0.87	—	0.72	—
Polyphosphate (mg/L as PO_4)	1.2	1.58	1.5	1.5	1.46	—	1.43	—	1.65	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	209	203	201	201	202	—	201	—	201	—
Hardness (mg/L as $CaCO_3$)	6	7	4	4	4	—	4	—	4	—
pH	7.17	7.13	7.21	7.24	7.29	—	7.34	—	7.28	—
Conductivity (μS/cm)	530	535	554	535	511	—	518	—	533	—
Temperature (°C)	20.5	20.9	22.9	21.1	20.8	—	19.6	—	20.8	—
Turbidity (ntu)	0.8	0.1	0.2	0.04	0.05	—	0.04	—	0.05	—

Table A9. Water Quality 3, Water Treatment 1, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	213	462	271	249	279	99	79	65	44	63
Copper (mg/L)	0.00	0.00	0.00	0.00	0.00	—	0.02	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	172	154	125	140	145	—	136	—	131	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	24	20	18	19	20	—	20	—	20	—
Hardness (mg/L as $CaCO_3$)	5	5	5	5	4	—	4	—	4	—
pH	7.76	7.42	7.56	7.55	7.57	—	7.41	—	7.53	—
Conductivity (μS/cm)	239	241	251	241	241	—	232	—	240	—
Temperature (°C)	20.5	20.8	22.9	21.1	21.0	—	19.4	—	20.8	—
Turbidity (ntu)	12	2	1.4	0.8	1.1	—	0.4	—	0.3	—

Table A10. Water Quality 3, Water Treatment 2, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	708	681	477	324	461	243	281	195	288	170
Copper (mg/L)	0.00	0.00	0.01	0.00	0.00	—	0.02	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	179	179	129	204	182	—	160	—	151	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	10.20	10.46	10.38	10.72	10.16	—	10.46	—	10.91	—
M Alkalinity (mg/L as $CaCO_3$)	30	23	23	21	22	—	23	—	23	—
Hardness (mg/L as $CaCO_3$)	10	6	5	4	4	—	5	—	4	—
pH	9.26	8.96	9.15	9.19	9.13	—	9.28	—	9.26	—
Conductivity (μS/cm)	246	249	258	247	241	—	239	—	246	—
Temperature (°C)	20.4	20.8	22.6	21.1	20.9	—	19.1	—	20.6	—
Turbidity (ntu)	52	4	4	3.5	3.4	—	2.0	—	1.7	—

Table A11. Water Quality 3, Water Treatment 3, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	746	284	145	51	92	78	62	56	80	54
Copper (mg/L)	0.00	0.01	0.00	0.00	0.00	—	0.00	—	0.00	—
Zinc (mg/L)	0.40	0.44	0.39	0.44	0.44	—	0.42	—	0.44	—
Total Dissolved Solids (mg/L)	171	143	108	152	166	—	147	—	145	—
Orthophosphate (mg/L as PO_4)	1.75	150	1.72	1.80	1.64	—	1.83	—	1.70	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	19	19	19	20	21	—	20	—	21	—
Hardness (mg/L as $CaCO_3$)	5	6	4	4	4	—	4	—	4	—
pH	7.73	7.85	7.76	7.93	7.71	—	7.68	—	7.45	—
Conductivity (μS/cm)	238	240	248	238	238	—	231	—	234	—
Temperature (°C)	20.4	20.9	22.5	20.9	20.8	—	19.3	—	20.2	—
Turbidity (ntu)	9.3	1.7	2.2	1.4	1.0	—	1.3	—	1.4	—

Table A12. Water Quality 3, Water Treatment 4, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	919	242	290	346	262	241	242	180	124	202
Copper (mg/L)	0.00	0.01	0.00	0.00	0.00	—	0.00	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	162	144	122	156	168	—	144	—	143	—
Orthophosphate (mg/L as PO_4)	1.01	1.09	1.11	1.10	1.58	—	1.21	—	1.40	—
Polyphosphate (mg/L as PO_4)	1.1	1.63	1.12	1.2	0.55	—	1.03	—	0.83	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	21	20	19	21	22	—	22	—	20	—
Hardness (mg/L as $CaCO_3$)	6	5	5	5	5	—	4	—	4	—
pH	7.91	7.84	7.83	7.83	7.70	—	7.61	—	7.62	—
Conductivity (μS/cm)	238	240	247	239	238	—	231	—	237	—
Temperature (°C)	20.4	20.9	22.5	20.9	20.9	—	19.3	—	20.4	—
Turbidity (ntu)	5.0	0.7	1.1	0.3	0.4	—	0.2	—	0.2	—

Table A13. Water Quality 4, Water Treatment 1, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	449	154	64	69	649	67	71	95	289	68
Copper (mg/L)	0.00	0.01	0.00	0.00	0.00	—	0.00	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	388	338	337	367	381	—	359	—	338	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	205	204	201	201	201	—	202	—	200	—
Hardness (mg/L as $CaCO_3$)	5	4	5	4	4	—	4	—	4	—
pH	7.99	7.99	8.11	8.07	8.07	—	8.07	—	8.24	—
Conductivity (μS/cm)	529	534	554	530	528	—	515	—	530	—
Temperature (°C)	20.4	20.8	22.6	20.9	20.9	—	19.2	—	20.5	—
Turbidity (ntu)	3.9	2.2	5	3.5	3.5	—	2.5	—	3.5	—

Table A14. Water Quality 4, Water Treatment 2, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	367	510	97	142	297	98	107	97	84	205
Copper (mg/L)	0.00	0.01	0.00	0.00	0.00	—	0.00	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	406	366	354	383	379	—	361	—	347	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	9.61	10.06	9.83	10.61	10.35	—	10.60	—	10.58	—
M Alkalinity (mg/L as $CaCO_3$)	200	205	203	202	201	—	204	—	200	—
Hardness (mg/L as $CaCO_3$)	6	5	4	5	4	—	4	—	4	—
pH	8.34	8.83	8.42	8.47	8.49	—	8.56	—	8.60	—
Conductivity (μS/cm)	536	542	537	538	529	—	503	—	540	—
Temperature (°C)	20.3	20.9	22.6	20.9	20.7	—	19.1	—	20.8	—
Turbidity (ntu)	8.4	4.0	5	3.0	3.0	—	2.0	—	1.0	—

Table A15. Water Quality 4, Water Treatment 3, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	84	24	18	16	119	31	40	17	23	18
Copper (mg/L)	0.00	0.00	0.00	0.00	0.00	—	0.00	—	0.00	—
Zinc (mg/L)	0.44	0.39	0.44	0.43	0.43	—	0.54	—	0.44	—
Total Dissolved Solids (mg/L)	374	346	343	352	381	—	348	—	356	—
Orthophosphate (mg/L as PO_4)	1.65	1.73	1.71	2.05	1.67	—	1.82	—	1.60	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	206	203	202	201	202	—	203	—	202	—
Hardness (mg/L as $CaCO_3$)	4	4	4	4	4	—	4	—	5	—
pH	7.87	8.34	8.42	8.00	8.06	—	8.09	—	8.09	—
Conductivity (μS/cm)	530	536	551	465	517	—	513	—	531	—
Temperature (°C)	20.5	21.0	22.6	20.9	20.9	—	19.2	—	20.7	—
Turbidity (ntu)	1.0	0.4	1	0.4	0.6	—	0.4	—	0.4	—

Table A16. Water Quality 4, Water Treatment 4, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	342	237	72	78	88	102	186	100	553	117
Copper (mg/L)	0.00	0.02	0.00	0.00	0.00	—	0.00	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	365	356	329	366	362	—	353	—	358	—
Orthophosphate (mg/L as PO_4)	0.81	0.78	0.80	0.65	0.73	—	0.88	—	0.85	—
Polyphosphate (mg/L as PO_4)	1.4	1.74	1.4	1.6	1.46	—	1.50	—	1.71	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	207	201	203	203	201	—	202	—	200	—
Hardness (mg/L as $CaCO_3$)	5	5	4	4	4	—	5	—	4	—
pH	7.90	8.07	8.11	8.13	8.11	—	8.16	—	8.22	—
Conductivity (μS/cm)	529	537	556	527	530	—	515	—	533	—
Temperature (°C)	20.6	21.0	22.8	21.1	20.9	—	19.3	—	20.7	—
Turbidity (ntu)	0.4	0.8	1.1	1.0	1.3	—	0.8	—	0.6	—

Table A17. Water Quality 5, Water Treatment 1, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	4215	1480	320	216	231	93	83	78	79	70
Copper (mg/L)	0.00	0.00	0.01	0.00	0.00	—	0.00	—	0.01	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	305	290	349	250	318	—	323	—	312	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	20	19	20	21	20	—	22	—	20	—
Hardness (mg/L as $CaCO_3$)	98	97	98	99	99	—	98	—	97	—
pH	7.08	7.35	7.39	7.68	7.54	—	7.56	—	7.42	—
Conductivity (μS/cm)	245	248	257	247	245	—	237	—	246	—
Temperature (°C)	20.6	21.0	23.0	21.1	20.9	—	19.43	—	20.8	—
Turbidity (ntu)	11.0	2.0	6.0	0.8	0.3	—	0.2	—	0.1	—

Table A18. Water Quality 5, Water Treatment 2, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	461	603	169	151	1154	113	774	110	114	127
Copper (mg/L)	0.00	0.00	0.00	0.00	0.00	—	0.00	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	304	266	228	260	293	—	303	—	315	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	10.68	10.67	10.38	10.56	10.57	—	11.16	—	10.90	—
M Alkalinity (mg/L as $CaCO_3$)	20	22	21	23	22	—	23	—	23	—
Hardness (mg/L as $CaCO_3$)	98	96	99	98	98	—	97	—	98	—
pH	8.37	8.15	8.27	8.21	8.23	—	8.62	—	8.70	—
Conductivity (μS/cm)	249	252	261	251	249	—	242	—	249	—
Temperature (°C)	20.4	21.0	22.7	20.9	20.7	—	19.3	—	20.6	—
Turbidity (ntu)	6.2	5.0	3.0	3.5	5.0	—	2.0	—	1.0	—

Table A19. Water Quality 5, Water Treatment 3, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	100	127	141	52	134	68	205	73	114	54
Copper (mg/L)	0.00	0.00	0.01	0.00	0.00	—	0.00	—	0.00	—
Zinc (mg/L)	0.43	0.55	0.39	0.44	0.43	—	0.65	—	0.43	—
Total Dissolved Solids (mg/L)	340	286	230	246	306	—	316	—	331	—
Orthophosphate (mg/L as PO_4)	1.67	1.63	1.66	1.74	1.63	—	1.70	—	1.63	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	17	19	20	20	19	—	23	—	21	—
Hardness (mg/L as $CaCO_3$)	97	98	97	98	97	—	99	—	99	—
pH	6.98	7.25	7.11	7.49	7.34	—	7.48	—	7.22	—
Conductivity (μS/cm)	243	246	254	243	244	—	236	—	242	—
Temperature (°C)	20.2	21.0	22.6	20.9	20.8	—	19.2	—	20.5	—
Turbidity (ntu)	8.0	2.4	2.6	2.0	2.1	—	1.7	—	1.4	—

Table A20. Water Quality 5, Water Treatment 4, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	389	214	389	345	299	210	230	174	224	200
Copper (mg/L)	0.00	0.01	0.01	0.00	0.00	—	0.00	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	356	280	232	247	347	—	291	—	327	—
Orthophosphate (mg/L as PO_4)	0.98	1.00	1.13	0.96	1.12	—	0.99	—	1.10	—
Polyphosphate (mg/L as PO_4)	1.2	1.24	1.10	1.3	1.07	—	1.29	—	1.12	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	24	19	18	20	21	—	21	—	22	—
Hardness (mg/L as $CaCO_3$)	95	96	97	98	97	—	98	—	99	—
pH	7.11	7.26	7.17	7.35	7.38	—	7.48	—	7.24	—
Conductivity (μS/cm)	241	248	254	244	244	—	236	—	240	—
Temperature (°C)	20.3	21.1	22.6	20.8	20.8	—	19.2	—	20.5	—
Turbidity (ntu)	1.0	0.3	0.6	0.1	0.12	—	0.1	—	0.2	—

Table A21. Water Quality 6, Water Treatment 1, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	125	183	39	65	264	67	178	64	550	58
Copper (mg/L)	0.00	0.00	0.02	0.00	0.00	—	0.01	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	379	355	382	323	389	—	339	—	454	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	208	205	203	201	201	—	202	—	202	—
Hardness (mg/L as $CaCO_3$)	98	97	97	98	97	—	97	—	98	—
pH	7.18	7.20	7.24	7.27	7.29	—	7.36	—	7.26	—
Conductivity (μS/cm)	531	540	558	532	530	—	517	—	534	—
Temperature (°C)	20.2	21.0	22.7	21.0	20.7	—	19.2	—	20.5	—
Turbidity (ntu)	1.2	0.4	1.7	6.0	5.3	—	0.6	—	5.2	—

Table A22. Water Quality 6, Water Treatment 2, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	90	354	56	42	491	113	112	162	287	96
Copper (mg/L)	0.00	0.00	0.01	0.00	0.00	—	0.01	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	387	355	404	342	390	—	331	—	429	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	8.84	9.22	9.63	10.26	10.05	—	10.60	—	11.36	—
M Alkalinity (mg/L as $CaCO_3$)	205	209	204	203	203	—	203	—	204	—
Hardness (mg/L as $CaCO_3$)	96	98	98	98	98	—	98	—	99	—
pH	7.23	7.26	7.29	7.30	7.35	—	7.46	—	7.32	—
Conductivity (μS/cm)	536	540	561	542	537	—	522	—	534	—
Temperature (°C)	20.3	21.1	22.6	20.9	20.8	—	19.3	—	20.7	—
Turbidity (ntu)	1.6	2.0	1.8	1.0	1.2	—	1.2	—	1.8	—

Table A23. Water Quality 6, Water Treatment 3, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	79	45	48	43	242	43	70	49	82	38
Copper (mg/L)	0.00	0.00	0.00	0.00	0.00	—	0.01	—	0.00	—
Zinc (mg/L)	0.43	0.36	0.39	0.45	0.43	—	0.93	—	0.41	—
Total Dissolved Solids (mg/L)	380	330	359	343	387	—	338	—	376	—
Orthophosphate (mg/L as PO_4)	1.67	1.65	1.68	1.83	1.66	—	1.69	—	1.67	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	200	201	203	201	201	—	202	—	202	—
Hardness (mg/L as $CaCO_3$)	97	98	101	98	98	—	95	—	97	—
pH	7.16	7.16	7.20	7.21	7.24	—	7.33	—	7.23	—
Conductivity (μS/cm)	524	540	556	534	531	—	516	—	535	—
Temperature (°C)	20.3	21.1	22.6	20.9	20.7	—	19.3	—	20.8	—
Turbidity (ntu)	2.4	1.1	1.8	1.6	2.0	—	1.2	—	1.6	—

Table A24. Water Quality 6, Water Treatment 4, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	210	282	78	108	82	64	109	89	275	84
Copper (mg/L)	0.00	0.00	0.01	0.00	0.00	—	0.01	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	370	308	360	338	381	—	333	—	377	—
Orthophosphate (mg/L as PO_4)	0.98	0.81	0.80	0.77	0.84	—	0.91	—	0.71	—
Polyphosphate (mg/L as PO_4)	1.2	1.49	1.41	1.4	1.32	—	1.35	—	1.58	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	205	200	202	202	200	—	203	—	202	—
Hardness (mg/L as $CaCO_3$)	96	96	98	98	97	—	96	—	96	—
pH	7.15	7.18	7.22	7.23	7.26	—	7.35	—	7.25	—
Conductivity (μS/cm)	530	537	558	539	534	—	518	—	536	—
Temperature (°C)	20.5	21.2	22.8	21.1	20.9	—	19.6	—	20.9	—
Turbidity (ntu)	0.7	1.2	0.7	0.7	0.6	—	0.8	—	0.8	—

Table A25. Water Quality 7, Water Treatment 1, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	227	197	233	172	175	60	55	51	52	79
Copper (mg/L)	0.00	0.00	0.01	0.00	0.00	—	0.01	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	340	276	259	334	327	—	285	—	290	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	23	20	18	21	21	—	20	—	21	—
Hardness (mg/L as $CaCO_3$)	98	99	97	99	97	—	98	—	97	—
pH	7.98	7.46	7.49	7.61	7.48	—	7.63	—	7.60	—
Conductivity (μS/cm)	244	247	258	248	244	—	240	—	246	—
Temperature (°C)	20.8	21.2	23.3	21.3	20.9	—	19.7	—	21.1	—
Turbidity (ntu)	5.2	2.0	1.5	1.0	0.8	—	0.4	—	0.1	—

Table A26. Water Quality 7, Water Treatment 2, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	860	140	200	118	721	143	314	172	432	77
Copper (mg/L)	0.00	0.00	0.00	0.00	0.00	—	0.01	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	340	271	256	358	331	—	302	—	322	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	9.82	10.46	10.49	10.53	10.39	—	10.45	—	11.36	—
M Alkalinity (mg/L as $CaCO_3$)	24	23	20	22	22	—	22	—	24	—
Hardness (mg/L as $CaCO_3$)	97	98	98	98	98	—	96	—	99	—
pH	9.13	9.09	8.85	8.95	8.98	—	9.09	—	9.07	—
Conductivity (μS/cm)	249	252	261	247	243	—	243	—	248	—
Temperature (°C)	20.6	21.1	23.0	21.1	21.0	—	19.7	—	20.8	—
Turbidity (ntu)	14	12	10	6.0	4.5	—	1.5	—	2.0	—

Table A27. Water Quality 7, Water Treatment 3, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	82	755	109	44	101	51	69	31	83	30
Copper (mg/L)	0.00	0.00	0.00	0.00	0.00	—	0.00	—	0.00	—
Zinc (mg/L)	0.37	0.36	0.38	0.39	0.39	—	0.47	—	0.39	—
Total Dissolved Solids (mg/L)	359	280	260	243	328	—	307	—	274	—
Orthophosphate (mg/L as PO_4)	1.67	1.63	1.68	1.71	1.55	—	1.68	—	1.69	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	20	18	19	19	20	—	21	—	20	—
Hardness (mg/L as $CaCO_3$)	97	97	97	99	99	—	99	—	97	—
pH	7.60	7.65	7.61	7.68	7.81	—	7.67	—	7.66	—
Conductivity (μS/cm)	244	244	254	245	244	—	238	—	243	—
Temperature (°C)	20.6	21.2	22.9	21.2	21.0	—	19.6	—	20.7	—
Turbidity (ntu)	6.7	4.0	2.3	2.0	1.1	—	1.0	—	0.9	—

Table A28. Water Quality 7, Water Treatment 4, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	6256	724	381	224	200	224	197	261	234	226
Copper (mg/L)	0.00	0.00	0.00	0.00	0.00	—	0.00	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	358	283	244	229	326	—	280	—	281	—
Orthophosphate (mg/L as PO_4)	0.84	0.84	0.86	0.85	0.96	—	0.92	—	1.00	—
Polyphosphate (mg/L as PO_4)	1.0	1.39	1.3	1.4	1.22	—	1.42	—	1.06	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	19	18	19	20	20	—	20	—	22	—
Hardness (mg/L as $CaCO_3$)	99	97	96	98	97	—	97	—	96	—
pH	7.82	7.88	7.88	7.94	7.82	—	7.78	—	7.70	—
Conductivity (μS/cm)	245	246	255	246	243	—	237	—	242	—
Temperature (°C)	20.6	21.2	22.9	21.1	21.0	—	19.7	—	20.7	—
Turbidity (ntu)	21	3.0	1.3	0.5	0.4	—	0.3	—	0.3	—

Table A29. Water Quality 8, Water Treatment 1, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	515	49	69	50	827	57	78	59	823	68
Copper (mg/L)	0.00	0.00	0.00	0.00	0.00	—	0.00	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	372	335	333	335	357	—	335	—	344	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	204	200	202	202	201	—	203	—	201	—
Hardness (mg/L as $CaCO_3$)	98	96	99	98	98	—	96	—	96	—
pH	8.06	8.03	8.05	8.08	8.10	—	8.14	—	8.14	—
Conductivity (μS/cm)	535	538	559	536	533	—	519	—	535	—
Temperature (°C)	20.6	21.1	23.1	21.2	21.0	—	19.6	—	20.8	—
Turbidity (ntu)	5.9	4.0	7.0	5.0	4.5	—	3.0	—	3.4	—

Table A30. Water Quality 8, Water Treatment 2, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	269	60	90	56	303	91	101	112	175	82
Copper (mg/L)	0.00	0.00	0.00	0.00	0.00	—	0.01	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	367	355	362	340	349	—	340	—	379	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	9.46	10.69	10.34	10.54	10.36	—	10.57	—	11.06	—
M Alkalinity (mg/L as $CaCO_3$)	206	202	201	201	201	—	202	—	203	—
Hardness (mg/L as $CaCO_3$)	98	97	97	99	97	—	98	—	97	—
pH	8.33	8.35	8.32	8.41	8.41	—	8.48	—	8.46	—
Conductivity (μS/cm)	540	544	564	538	514	—	525	—	540	—
Temperature (°C)	20.7	21.2	22.9	21.2	20.8	—	19.6	—	21.0	—
Turbidity (ntu)	3.2	2.1	4.0	3.0	3.0	—	0.8	—	1.1	—

Table A31. Water Quality 8, Water Treatment 3, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	260	61	18	10	31	27	25	7	277	14
Copper (mg/L)	0.00	0.00	0.01	0.00	0.00	—	0.00	—	0.00	—
Zinc (mg/L)	0.39	0.40	0.58	0.38	0.48	—	0.46	—	0.41	—
Total Dissolved Solids (mg/L)	379	339	356	389	370	—	310	—	359	—
Orthophosphate (mg/L as PO_4)	1.66	1.81	1.77	1.83	1.54	—	1.69	—	1.73	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	201	201	201	202	200	—	203	—	200	—
Hardness (mg/L as $CaCO_3$)	97	97	98	98	97	—	98	—	96	—
pH	7.93	7.99	8.10	8.05	8.07	—	8.09	—	8.01	—
Conductivity (μS/cm)	536	541	559	537	532	—	521	—	542	—
Temperature (°C)	20.7	21.3	22.9	21.2	21.0	—	19.8	—	20.9	—
Turbidity (ntu)	1.7	0.4	0.4	0.6	0.4	—	0.7	—	0.4	—

Table A32. Water Quality 8, Water Treatment 4, 7/18/94 - 7/29/94.

Date Sampled	7/18/94	7/19/94	7/20/94	7/21/94	7/22/94	7/25/94	7/26/94	7/27/94	7/28/94	7/29/94
Lead (μg/L)	361	237	80	57	74	70	101	58	246	69
Copper (mg/L)	0.00	0.00	0.00	0.00	0.00	—	0.01	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	384	362	343	368	359	—	341	—	369	—
Orthophosphate (mg/L as PO_4)	0.62	0.84	0.79	0.64	0.68	—	0.92	—	0.74	—
Polyphosphate (mg/L as PO_4)	2.0	1.58	1.5	1.6	1.50	—	1.43	—	1.54	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	208	202	202	202	202	—	202	—	202	—
Hardness (mg/L as $CaCO_3$)	98	94	96	98	97	—	97	—	98	—
pH	8.03	8.05	8.10	8.10	8.11	—	8.16	—	8.13	—
Conductivity (μS/cm)	540	539	554	540	536	—	526	—	537	—
Temperature (°C)	20.7	21.4	23.1	21.4	21.2	—	20.1	—	21.1	—
Turbidity (ntu)	0.7	1.4	1.1	0.8	1.0	—	0.8	—	0.7	—

Table A33. Water Quality 1, Water Treatment 1, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	21	32	42	7	13	0	13	17	10	18
Copper (mg/L)	—	0.00	—	0.03	—	—	0.04	—	0.05	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	—	154	—	166	—	—	131	—	193	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	—	21	—	21	—	—	20	—	20	—
Hardness (mg/L as $CaCO_3$)	—	4	—	4	—	—	4	—	4	—
pH	—	7.08	—	7.81	—	—	7.80	—	7.33	—
Conductivity (μS/cm)	—	241	—	242	—	—	218	—	246	—
Temperature (°C)	—	21.6	—	21.8	—	—	21.5	—	22.2	—
Turbidity (ntu)	—	0.14	—	0.05	—	—	0.07	—	0.09	—

Table A34. Water Quality 1, Water Treatment 2, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	25	25	8	22	11	10	10	12	16	55
Copper (mg/L)	—	0.01	—	0.00	—	—	0.01	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	—	170	—	191	—	—	174	—	181	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	10.81	—	10.60	—	—	11.17	—	9.61	—
M Alkalinity (mg/L as $CaCO_3$)	—	22	—	23	—	—	23	—	27	—
Hardness (mg/L as $CaCO_3$)	—	5	—	4	—	—	4	—	5	—
pH	—	8.27	—	8.68	—	—	8.91	—	8.83	—
Conductivity (μS/cm)	—	246	—	213	—	—	245	—	252	—
Temperature (°C)	—	21.2	—	21.5	—	—	21.2	—	22.1	—
Turbidity (ntu)	—	0.06	—	0.05	—	—	0.06	—	0.06	—

Table A35. Water Quality 1, Water Treatment 3, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	11	13	1	0	0	0	29	0	6	7
Copper (mg/L)	—	0.04	—	0.00	—	—	0.03	—	0.00	—
Zinc (mg/L)	—	0.43	—	0.45	—	—	0.47	—	0.48	—
Total Dissolved Solids (mg/L)	—	151	—	173	—	—	142	—	162	—
Orthophosphate (mg/L as PO_4)	—	1.71	—	1.85	—	—	1.92	—	1.61	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	—	20	—	20	—	—	20	—	20	—
Hardness (mg/L as $CaCO_3$)	—	4	—	4	—	—	4	—	8	—
pH	—	6.86	—	7.15	—	—	7.15	—	7.21	—
Conductivity (μS/cm)	—	239	—	240	—	—	239	—	245	—
Temperature (°C)	—	21.3	—	21.4	—	—	21.2	—	22.1	—
Turbidity (ntu)	—	0.2	—	0.08	—	—	0.1	—	0.1	—

Table A36. Water Quality 1, Water Treatment 4, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	16	17	14	0	10	3	14	5	17	15
Copper (mg/L)	—	0.03	—	0.01	—	—	0.03	—	0.01	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	—	164	—	167	—	—	151	—	185	—
Orthophosphate (mg/L as PO_4)	—	1.07	—	1.19	—	—	1.03	—	1.10	—
Polyphosphate (mg/L as PO_4)	—	1.12	—	1.39	—	—	1.75	—	1.35	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	—	21	—	20	—	—	21	—	20	—
Hardness (mg/L as $CaCO_3$)	—	4	—	4	—	—	4	—	8	—
pH	—	6.98	—	7.21	—	—	7.30	—	7.30	—
Conductivity (μS/cm)	—	238	—	242	—	—	239	—	230	—
Temperature (°C)	—	21.2	—	21.4	—	—	21.2	—	22.1	—
Turbidity (ntu)	—	0.06	—	0.04	—	—	0.07	—	0.07	—

Table A37. Water Quality 2, Water Treatment 1, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	26	70	37	23	13	11	41	13	35	20
Copper (mg/L)	—	0.07	—	0.01	—	—	0.08	—	0.05	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	—	351	—	375	—	—	354	—	373	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	—	203	—	201	—	—	201	—	200	—
Hardness (mg/L as $CaCO_3$)	—	4	—	4	—	—	4	—	4	—
pH	—	7.09	—	7.20	—	—	7.34	—	7.36	—
Conductivity (μS/cm)	—	537	—	525	—	—	539	—	547	—
Temperature (°C)	—	21.2	—	21.4	—	—	21.2	—	22.0	—
Turbidity (ntu)	—	0.7	—	0.13	—	—	0.13	—	0.2	—

Table A38. Water Quality 2, Water Treatment 2, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	14	31	3	0	11	2	16	53	18	11
Copper (mg/L)	—	0.13	—	0.15	—	—	0.08	—	0.06	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	—	375	—	389	—	—	351	—	404	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	10.53	—	9.42	—	—	10.86	—	9.84	—
M Alkalinity (mg/L as $CaCO_3$)	—	203	—	203	—	—	203	—	203	—
Hardness (mg/L as $CaCO_3$)	—	5	—	4	—	—	4	—	6	—
pH	—	7.10	—	7.24	—	—	7.42	—	7.34	—
Conductivity (μS/cm)	—	522	—	513	—	—	543	—	556	—
Temperature (°C)	—	21.1	—	21.4	—	—	21.2	—	22.1	—
Turbidity (ntu)	—	0.08	—	0.07	—	—	0.1	—	0.1	—

Table A39. Water Quality 2, Water Treatment 3, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	12	30	18	0	0	2	13	5	17	12
Copper (mg/L)	—	0.05	—	0.00	—	—	0.05	—	0.00	—
Zinc (mg/L)	—	0.44	—	0.49	—	—	0.46	—	0.47	—
Total Dissolved Solids (mg/L)	—	368	—	359	—	—	338	—	391	—
Orthophosphate (mg/L as PO_4)	—	1.78	—	1.88	—	—	1.84	—	1.77	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	—	201	—	200	—	—	202	—	202	—
Hardness (mg/L as $CaCO_3$)	—	4	—	4	—	—	4	—	5	—
pH	—	7.03	—	7.17	—	—	7.34	—	7.35	—
Conductivity (μS/cm)	—	535	—	540	—	—	537	—	547	—
Temperature (°C)	—	21.1	—	21.4	—	—	21.2	—	22.1	—
Turbidity (ntu)	—	0.6	—	0.15	—	—	0.1	—	0.2	—

Table A40. Water Quality 2, Water Treatment 4, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	20	39	31	5	11	2	20	7	26	19
Copper (mg/L)	—	0.14	—	0.14	—	—	0.10	—	0.09	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	—	340	—	378	—	—	382	—	381	—
Orthophosphate (mg/L as PO_4)	—	0.81	—	0.92	—	—	0.80	—	0.70	—
Polyphosphate (mg/L as PO_4)	—	1.38	—	1.71	—	—	1.76	—	1.64	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	—	202	—	202	—	—	201	—	200	—
Hardness (mg/L as $CaCO_3$)	—	4	—	4	—	—	4	—	5	—
pH	—	7.06	—	7.16	—	—	7.34	—	7.38	—
Conductivity (μS/cm)	—	535	—	525	—	—	537	—	533	—
Temperature (°C)	—	21.1	—	21.4	—	—	21.2	—	22.1	—
Turbidity (ntu)	—	0.05	—	0.06	—	—	0.05	—	0.05	—

Table A41. Water Quality 3, Water Treatment 1, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	33	76	42	18	38	38	24	8	32	22
Copper (mg/L)	—	0.00	—	0.00	—	—	0.00	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	—	124	—	164	—	—	135	—	159	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	—	21	—	20	—	—	22	—	22	—
Hardness (mg/L as $CaCO_3$)	—	5	—	4	—	—	7	—	5	—
pH	—	7.78	—	7.62	—	—	7.73	—	7.74	—
Conductivity (μS/cm)	—	240	—	208	—	—	244	—	243	—
Temperature (°C)	—	21.2	—	21.5	—	—	21.2	—	22.1	—
Turbidity (ntu)	—	0.2	—	0.1	—	—	0.06	—	0.1	—

Table A42. Water Quality 3, Water Treatment 2, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	152	374	267	326	282	109	280	304	241	110
Copper (mg/L)	—	0.00	—	0.00	—	—	0.00	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	—	132	—	172	—	—	157	—	169	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	10.91	—	10.70	—	—	11.47	—	9.54	—
M Alkalinity (mg/L as $CaCO_3$)	—	22	—	22	—	—	25	—	24	—
Hardness (mg/L as $CaCO_3$)	—	4	—	4	—	—	4	—	6	—
pH	—	9.25	—	9.16	—	—	9.23	—	9.14	—
Conductivity (μS/cm)	—	248	—	215	—	—	250	—	254	—
Temperature (°C)	—	21.1	—	21.4	—	—	21.1	—	22.0	—
Turbidity (ntu)	—	1.5	—	2.8	—	—	1.0	—	1.1	—

Table A43. Water Quality 3, Water Treatment 3, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	46	77	39	60	25	40	48	34	45	39
Copper (mg/L)	—	0.00	—	0.00	—	—	0.00	—	0.00	—
Zinc (mg/L)	—	0.44	—	0.49	—	—	0.45	—	0.46	—
Total Dissolved Solids (mg/L)	—	145	—	156	—	—	132	—	150	—
Orthophosphate (mg/L as PO_4)	—	1.65	—	1.80	—	—	1.79	—	1.79	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	—	20	—	21	—	—	23	—	20	—
Hardness (mg/L as $CaCO_3$)	—	4	—	4	—	—	5	—	5	—
pH	—	7.52	—	7.58	—	—	7.44	—	7.46	—
Conductivity (μS/cm)	—	239	—	241	—	—	241	—	240	—
Temperature (°C)	—	21.0	—	21.3	—	—	21.1	—	22.0	—
Turbidity (ntu)	—	0.6	—	1.1	—	—	0.9	—	0.6	—

Table A44. Water Quality 3, Water Treatment 4, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	122	147	128	61	100	75	55	57	39	40
Copper (mg/L)	—	0.00	—	0.01	—	—	0.00	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	—	139	—	155	—	—	136	—	162	—
Orthophosphate (mg/L as PO_4)	—	0.80	—	0.98	—	—	0.88	—	0.91	—
Polyphosphate (mg/L as PO_4)	—	1.36	—	1.53	—	—	1.58	—	1.38	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	—	20	—	21	—	—	22	—	20	—
Hardness (mg/L as $CaCO_3$)	—	4	—	5	—	—	4	—	5	—
pH	—	7.79	—	7.67	—	—	7.74	—	7.73	—
Conductivity (μS/cm)	—	238	—	242	—	—	240	—	244	—
Temperature (°C)	—	21.1	—	21.4	—	—	21.0	—	22.0	—
Turbidity (ntu)	—	0.1	—	0.04	—	—	0.05	—	0.07	—

Table A45. Water Quality 4, Water Treatment 1, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	48	99	63	48	81	56	72	64	47	59
Copper (mg/L)	—	0.00	—	0.01	—	—	0.00	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	—	353	—	374	—	—	343	—	381	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	—	201	—	202	—	—	203	—	202	—
Hardness (mg/L as $CaCO_3$)	—	4	—	5	—	—	5	—	5	—
pH	—	8.15	—	8.13	—	—	8.24	—	8.27	—
Conductivity (μS/cm)	—	537	—	544	—	—	540	—	547	—
Temperature (°C)	—	21.1	—	21.4	—	—	21.1	—	22.0	—
Turbidity (ntu)	—	7.3	—	3.2	—	—	3.0	—	1.8	—

Table A46. Water Quality 4, Water Treatment 2, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	49	45	62	15	14	26	33	55	14	11
Copper (mg/L)	—	0.01	—	0.00	—	—	0.00	—	0.01	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	—	379	—	403	—	—	363	—	380	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	10.91	—	10.29	—	—	11.32	—	9.87	—
M Alkalinity (mg/L as $CaCO_3$)	—	200	—	202	—	—	201	—	206	—
Hardness (mg/L as $CaCO_3$)	—	4	—	4	—	—	4	—	5	—
pH	—	8.53	—	8.51	—	—	8.62	—	8.58	—
Conductivity (μS/cm)	—	533	—	550	—	—	545	—	547	—
Temperature (°C)	—	21.0	—	21.4	—	—	21.1	—	22.0	—
Turbidity (ntu)	—	0.7	—	0.6	—	—	0.1	—	0.1	—

Table A47. Water Quality 4, Water Treatment 3, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	22	29	16	0	1	9	16	23	11	8
Copper (mg/L)	—	0.00	—	0.00	—	—	0.00	—	0.00	—
Zinc (mg/L)	—	0.44	—	0.47	—	—	0.46	—	0.47	—
Total Dissolved Solids (mg/L)	—	356	—	371	—	—	336	—	377	—
Orthophosphate (mg/L as PO_4)	—	1.62	—	1.92	—	—	1.90	—	1.57	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	—	201	—	201	—	—	200	—	202	—
Hardness (mg/L as $CaCO_3$)	—	4	—	5	—	—	4	—	6	—
pH	—	8.06	—	8.03	—	—	8.13	—	8.14	—
Conductivity (μS/cm)	—	534	—	474	—	—	538	—	542	—
Temperature (°C)	—	21.0	—	21.3	—	—	21.1	—	21.9	—
Turbidity (ntu)	—	0.6	—	0.5	—	—	0.4	—	0.1	—

Table A48. Water Quality 4, Water Treatment 4, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	180	176	110	96	126	113	96	156	111	144
Copper (mg/L)	—	0.00	—	0.00	—	—	0.00	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	—	351	—	380	—	—	339	—	354	—
Orthophosphate (mg/L as PO_4)	—	0.75	—	0.92	—	—	0.86	—	0.65	—
Polyphosphate (mg/L as PO_4)	—	1.48	—	1.59	—	—	1.66	—	1.63	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	—	203	—	201	—	—	202	—	204	—
Hardness (mg/L as $CaCO_3$)	—	5	—	4	—	—	4	—	5	—
pH	—	8.15	—	8.14	—	—	8.23	—	8.26	—
Conductivity (μS/cm)	—	531	—	541	—	—	538	—	548	—
Temperature (°C)	—	21.1	—	21.4	—	—	21.1	—	22.0	—
Turbidity (ntu)	—	1.1	—	0.8	—	—	0.9	—	0.5	—

Table A49. Water Quality 5 Water Treatment 1, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	111	213	40	12	21	13	31	31	34	5
Copper (mg/L)	—	0.01	—	0.01	—	—	0.01	—	0.01	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	—	230	—	310	—	—	265	—	249	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	—	20	—	21	—	—	22	—	20	—
Hardness (mg/L as $CaCO_3$)	—	98	—	96	—	—	101	—	96	—
pH	—	7.47	—	7.51	—	—	7.64	—	7.65	—
Conductivity (μS/cm)	—	247	—	246	—	—	247	—	251	—
Temperature (°C)	—	21.2	—	21.4	—	—	21.1	—	22.0	—
Turbidity (ntu)	—	1.4	—	0.06	—	—	0.06	—	0.1	—

Table A50. Water Quality 5, Water Treatment 2, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	266	241	142	139	79	120	206	204	198	221
Copper (mg/L)	—	0.00	—	0.00	—	—	0.00	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	—	262	—	281	—	—	269	—	262	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	11.06	—	10.72	—	—	10.49	—	10.83	—
M Alkalinity (mg/L as $CaCO_3$)	—	21	—	22	—	—	23	—	25	—
Hardness (mg/L as $CaCO_3$)	—	96	—	97	—	—	97	—	95	—
pH	—	8.38	—	8.49	—	—	8.69	—	8.53	—
Conductivity (μS/cm)	—	251	—	250	—	—	251	—	249	—
Temperature (°C)	—	21.1	—	21.3	—	—	21.1	—	22.0	—
Turbidity (ntu)	—	0.9	—	1.0	—	—	0.7	—	0.15	—

Table A51. Water Quality 5, Water Treatment 3, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	44	30	16	0	0	0	17	11	14	6
Copper (mg/L)	—	0.00	—	0.00	—	—	0.00	—	0.00	—
Zinc (mg/L)	—	0.47	—	0.47	—	—	0.44	—	0.47	—
Total Dissolved Solids (mg/L)	—	331	—	268	—	—	279	—	226	—
Orthophosphate (mg/L as PO_4)	—	1.79	—	1.80	—	—	1.82	—	1.77	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	—	20	—	21	—	—	22	—	23	—
Hardness (mg/L as $CaCO_3$)	—	98	—	95	—	—	96	—	97	—
pH	—	7.16	—	7.06	—	—	7.29	—	7.28	—
Conductivity (μS/cm)	—	245	—	238	—	—	243	—	250	—
Temperature (°C)	—	21.0	—	21.3	—	—	21.1	—	22.0	—
Turbidity (ntu)	—	0.4	—	0.15	—	—	0.3	—	0.2	—

Table A52. Water Quality 5, Water Treatment 4, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	64	164	85	79	126	220	176	160	149	146
Copper (mg/L)	—	0.00	—	0.00	—	—	0.00	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	—	205	—	202	—	—	262	—	232	—
Orthophosphate (mg/L as PO_4)	—	0.80	—	0.92	—	—	0.92	—	0.91	—
Polyphosphate (mg/L as PO_4)	—	1.40	—	1.47	—	—	1.57	—	1.51	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	—	21	—	21	—	—	21	—	23	—
Hardness (mg/L as $CaCO_3$)	—	97	—	95	—	—	95	—	98	—
pH	—	7.25	—	7.16	—	—	7.35	—	7.37	—
Conductivity (μS/cm)	—	244	—	208	—	—	245	—	213	—
Temperature (°C)	—	21.1	—	21.3	—	—	21.1	—	22.0	—
Turbidity (ntu)	—	0.17	—	0.2	—	—	0.3	—	0.2	—

Table A53. Water Quality 6, Water Treatment 1, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	27	55	51	12	16	13	31	9	26	16
Copper (mg/L)	—	0.05	—	0.00	—	—	0.03	—	0.04	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	—	372	—	345	—	—	342	—	340	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	—	201	—	202	—	—	200	—	203	—
Hardness (mg/L as $CaCO_3$)	—	97	—	98	—	—	96	—	97	—
pH	—	7.27	—	7.22	—	—	7.41	—	7.46	—
Conductivity (μS/cm)	—	538	—	535	—	—	539	—	466	—
Temperature (°C)	—	21.1	—	21.4	—	—	21.1	—	22.0	—
Turbidity (ntu)	—	0.15	—	0.06	—	—	0.07	—	0.05	—

Table A54. Water Quality 6, Water Treatment 2, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	208	215	93	28	35	45	56	40	273	47
Copper (mg/L)	—	0.00	—	0.00	—	—	0.00	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	—	334	—	366	—	—	344	—	326	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	11.06	—	10.63	—	—	10.91	—	10.26	—
M Alkalinity (mg/L as $CaCO_3$)	—	203	—	203	—	—	202	—	203	—
Hardness (mg/L as $CaCO_3$)	—	98	—	96	—	—	95	—	96	—
pH	—	7.33	—	7.32	—	—	7.50	—	7.55	—
Conductivity (μS/cm)	—	539	—	536	—	—	542	—	554	—
Temperature (°C)	—	21.0	—	21.4	—	—	21.0	—	21.9	—
Turbidity (ntu)	—	0.9	—	1.5	—	—	0.6	—	0.3	—

Table A55. Water Quality 6, Water Treatment 3, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	35	135	54	16	10	12	32	13	132	21
Copper (mg/L)	—	0.00	—	0.00	—	—	0.00	—	0.00	—
Zinc (mg/L)	—	0.00	—	0.47	—	—	0.45	—	0.46	—
Total Dissolved Solids (mg/L)	—	359	—	341	—	—	338	—	345	—
Orthophosphate (mg/L as PO_4)	—	1.78	—	1.88	—	—	1.92	—	1.77	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	—	202	—	201	—	—	200	—	202	—
Hardness (mg/L as $CaCO_3$)	—	98	—	96	—	—	95	—	96	—
pH	—	7.25	—	7.22	—	—	7.38	—	7.42	—
Conductivity (μS/cm)	—	534	—	537	—	—	538	—	548	—
Temperature (°C)	—	21.1	—	21.4	—	—	21.0	—	21.9	—
Turbidity (ntu)	—	2.7	—	1.8	—	—	1.7	—	0.6	—

Table A56. Water Quality 6, Water Treatment 4, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	102	66	124	20	96	31	75	30	170	27
Copper (mg/L)	—	0.00	—	0.00	—	—	0.00	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	—	309	—	338	—	—	332	—	316	—
Orthophosphate (mg/L as PO_4)	—	0.75	—	0.89	—	—	0.91	—	0.76	—
Polyphosphate (mg/L as PO_4)	—	1.47	—	1.60	—	—	1.49	—	1.60	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	—	203	—	200	—	—	202	—	206	—
Hardness (mg/L as $CaCO_3$)	—	96	—	95	—	—	95	—	98	—
pH	—	7.27	—	7.24	—	—	7.40	—	7.45	—
Conductivity (μS/cm)	—	535	—	509	—	—	527	—	537	—
Temperature (°C)	—	21.1	—	21.5	—	—	21.1	—	22.0	—
Turbidity (ntu)	—	1.0	—	0.8	—	—	0.6	—	0.8	—

Table A57. Water Quality 7, Water Treatment 1, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	57	42	70	3	19	15	18	2	12	11
Copper (mg/L)	—	0.00	—	0.01	—	—	0.00	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	—	272	—	229	—	—	276	—	236	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	—	21	—	21	—	—	23	—	21	—
Hardness (mg/L as $CaCO_3$)	—	98	—	95	—	—	96	—	99	—
pH	—	7.71	—	7.59	—	—	7.73	—	7.76	—
Conductivity (μS/cm)	—	246	—	212	—	—	247	—	252	—
Temperature (°C)	—	21.2	—	21.5	—	—	21.1	—	22.0	—
Turbidity (ntu)	—	0.07	—	0.06	—	—	0.05	—	0.07	—

Table A58. Water Quality 7, Water Treatment 2, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	137	145	164	33	78	78	80	24	178	23
Copper (mg/L)	—	0.00	—	0.00	—	—	0.00	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	—	278	—	223	—	—	284	—	232	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	10.44	—	12.27	—	—	12.76	—	10.73	—
M Alkalinity (mg/L as $CaCO_3$)	—	23	—	23	—	—	24	—	26	—
Hardness (mg/L as $CaCO_3$)	—	97	—	95	—	—	96	—	95	—
pH	—	9.13	—	9.02	—	—	9.01	—	9.01	—
Conductivity (μS/cm)	—	252	—	249	—	—	252	—	254	—
Temperature (°C)	—	21.1	—	21.5	—	—	21.1	—	22.0	—
Turbidity (ntu)	—	0.6	—	0.9	—	—	0.5	—	0.4	—

Table A59. Water Quality 7, Water Treatment 3, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	21	515	61	12	4	12	18	12	23	6
Copper (mg/L)	—	0.00	—	0.00	—	—	0.00	—	0.00	—
Zinc (mg/L)	—	0.38	—	0.43	—	—	0.56	—	0.44	—
Total Dissolved Solids (mg/L)	—	277	—	336	—	—	269	—	231	—
Orthophosphate (mg/L as PO_4)	—	1.65	—	1.90	—	—	1.92	—	1.68	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	—	22	—	22	—	—	21	—	20	—
Hardness (mg/L as $CaCO_3$)	—	96	—	97	—	—	96	—	97	—
pH	—	7.61	—	7.51	—	—	7.53	—	7.50	—
Conductivity (μS/cm)	—	245	—	246	—	—	245	—	217	—
Temperature (°C)	—	21.1	—	21.5	—	—	21.1	—	22.1	—
Turbidity (ntu)	—	1.0	—	0.7	—	—	0.7	—	0.4	—

Table A60. Water Quality 7, Water Treatment 4, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	188	157	159	64	107	72	80	140	142	12
Copper (mg/L)	—	0.00	—	0.00	—	—	0.00	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	—	224	—	247	—	—	262	—	232	—
Orthophosphate (mg/L as PO_4)	—	0.90	—	0.99	—	—	0.92	—	0.76	—
Polyphosphate (mg/L as PO_4)	—	1.21	—	1.53	—	—	1.41	—	1.58	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	—	20	—	21	—	—	21	—	22	—
Hardness (mg/L as $CaCO_3$)	—	96	—	97	—	—	95	—	99	—
pH	—	7.86	—	7.79	—	—	7.79	—	7.71	—
Conductivity (μS/cm)	—	245	—	246	—	—	245	—	245	—
Temperature (°C)	—	21.1	—	21.5	—	—	21.0	—	22.1	—
Turbidity (ntu)	—	0.3	—	0.2	—	—	0.1	—	0.2	—

Table A61. Water Quality 8, Water Treatment 1, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	85	126	97	21	82	207	77	64	1026	66
Copper (mg/L)	—	0.00	—	0.00	—	—	0.00	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	—	396	—	341	—	—	385	—	336	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	—	202	—	203	—	—	201	—	208	—
Hardness (mg/L as $CaCO_3$)	—	97	—	96	—	—	96	—	98	—
pH	—	8.28	—	8.26	—	—	8.33	—	8.35	—
Conductivity (μS/cm)	—	529	—	542	—	—	535	—	546	—
Temperature (°C)	—	21.1	—	21.5	—	—	21.1	—	22.0	—
Turbidity (ntu)	—	3.0	—	3.0	—	—	1.6	—	2.0	—

Table A62. Water Quality 8, Water Treatment 2, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	45	314	182	59	107	69	221	55	149	25
Copper (mg/L)	—	0.00	—	0.00	—	—	0.00	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	—	368	—	331	—	—	351	—	322	—
Orthophosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	10.24	—	11.78	—	—	11.97	—	11.10	—
M Alkalinity (mg/L as $CaCO_3$)	—	202	—	204	—	—	203	—	207	—
Hardness (mg/L as $CaCO_3$)	—	96	—	96	—	—	95	—	95	—
pH	—	8.59	—	8.57	—	—	8.64	—	8.62	—
Conductivity (μS/cm)	—	537	—	547	—	—	538	—	495	—
Temperature (°C)	—	21.1	—	21.5	—	—	21.0	—	21.8	—
Turbidity (ntu)	—	1.2	—	0.6	—	—	1.7	—	0.5	—

Table A63. Water Quality 8, Water Treatment 3, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	10	15	27	12	0	3	11	10	26	4
Copper (mg/L)	—	0.00	—	0.00	—	—	0.00	—	0.00	—
Zinc (mg/L)	—	0.39	—	0.47	—	—	0.56	—	0.43	—
Total Dissolved Solids (mg/L)	—	375	—	341	—	—	391	—	328	—
Orthophosphate (mg/L as PO_4)	—	1.70	—	1.95	—	—	1.91	—	1.80	—
Polyphosphate (mg/L as PO_4)	—	—	—	—	—	—	—	—	—	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	—	202	—	202	—	—	201	—	200	—
Hardness (mg/L as $CaCO_3$)	—	97	—	97	—	—	96	—	98	—
pH	—	8.20	—	8.16	—	—	8.24	—	8.27	—
Conductivity (μS/cm)	—	537	—	543	—	—	533	—	545	—
Temperature (°C)	—	21.1	—	21.5	—	—	21.1	—	21.9	—
Turbidity (ntu)	—	0.2	—	0.5	—	—	0.7	—	0.2	—

Table A64. Water Quality 8, Water Treatment 4, 8/1/94 - 8/12/94.

Date Sampled	8/1/94	8/2/94	8/3/94	8/4/94	8/5/94	8/8/94	8/9/94	8/10/94	8/11/94	8/12/94
Lead (μg/L)	71	111	88	147	114	34	72	26	41	79
Copper (mg/L)	—	0.01	—	0.00	—	—	0.00	—	0.00	—
Zinc (mg/L)	—	—	—	—	—	—	—	—	—	—
Total Dissolved Solids (mg/L)	—	374	—	323	—	—	353	—	353	—
Orthophosphate (mg/L as PO_4)	—	0.76	—	0.78	—	—	0.89	—	0.61	—
Polyphosphate (mg/L as PO_4)	—	1.71	—	1.55	—	—	1.52	—	1.72	—
Silicate (mg/L as SiO_2)	—	—	—	—	—	—	—	—	—	—
M Alkalinity (mg/L as $CaCO_3$)	—	200	—	203	—	—	203	—	202	—
Hardness (mg/L as $CaCO_3$)	—	96	—	97	—	—	97	—	95	—
pH	—	8.30	—	8.28	—	—	8.35	—	8.37	—
Conductivity (μS/cm)	—	537	—	532	—	—	535	—	535	—
Temperature (°C)	—	21.2	—	21.6	—	—	21.1	—	21.9	—
Turbidity (ntu)	—	0.6	—	0.8	—	—	0.5	—	0.5	—

Appendix B: Wilcoxon Signed Rank Test Results

Counts of Differences (Row Variable Greater Than Column)

	WQ1WT1	WQ1WT2	WQ1WT3	WQ1WT3
WQ1WT1	0	12	17	15
WQ1WT2	8	0	18	13
WQ1WT3	2	2	0	2
WQ1WT4	5	7	17	0

Z = (Sum of Signed Ranks)/Square Root (Sum of Squared Ranks)

	WQ1WT1	WQ1WT2	WQ1WT3	WQ1WT3
WQ1WT1	0.0000			
WQ1WT2	-0.7650	0.0000		
WQ1WT3	-2.8170	-2.8200	0.0000	
WQ1WT4	-2.2220	-1.6250	2.5760	0.0000

Two-Sided Probability Using Normal Approximation

	WQ1WT1	WQ1WT2	WQ1WT3	WQ1WT3
WQ1WT1	1.0000			
WQ1WT2	0.4440	0.0000		
WQ1WT3	0.0050	0.0050	0.0000	
WQ1WT4	0.0260	0.1040	0.0100	1.0000

8 Water Quality 1, Water treatment 2 lead values were greater than Water Quality 1, Water Treatment 1 values,
12 Water Quality 1, Water treatment 1 lead values were greater than Water Quality 1, Water Treatment 2 values,

17 Water Quality 1, Water treatment 1 lead values were greater than Water Quality 1, Water Treatment 3 values,
2 Water Quality 1, Water treatment 3 lead values were greater than Water Quality 1, Water Treatment 1 values,

15 Water Quality 1, Water treatment 1 lead values were greater than Water Quality 1, Water Treatment 4 values,
5 Water Quality 1, Water treatment 4 lead values were greater than Water Quality 1, Water Treatment 1 values,

18 Water Quality 1, Water treatment 2 lead values were greater than Water Quality 1, Water Treatment 3 values,
2 Water Quality 1, Water treatment 3 lead values were greater than Water Quality 1, Water Treatment 2 values,

13 Water Quality 1, Water treatment 2 lead values were greater than Water Quality 1, Water Treatment 4 values,
7 Water Quality 1, Water treatment 4 lead values were greater than Water Quality 1, Water Treatment 2 values,

2 Water Quality 1, Water treatment 3 lead values were greater than Water Quality 1, Water Treatment 4 values,
17 Water Quality 1, Water treatment 4 lead values were greater than Water Quality 1, Water Treatment 3 values,

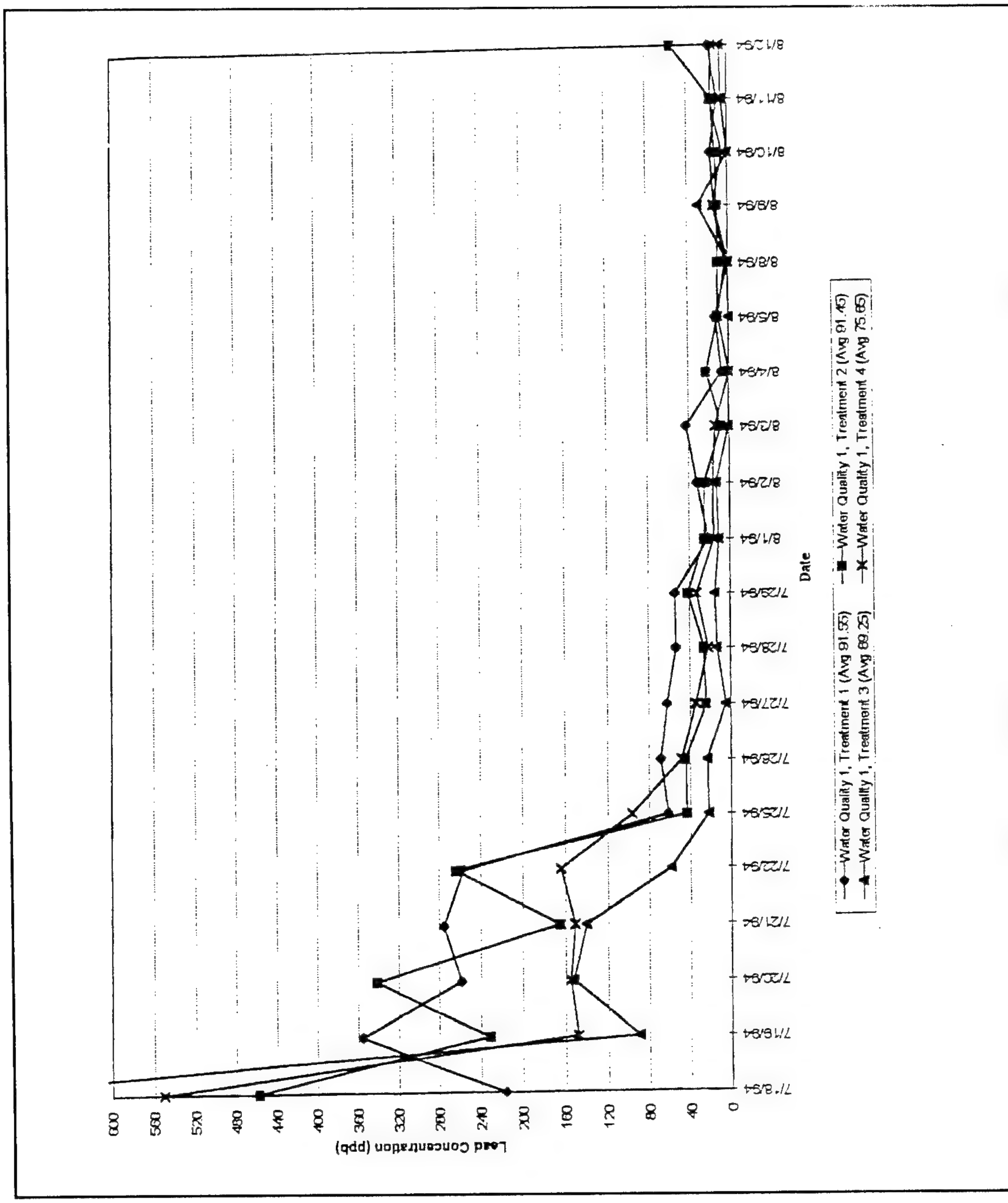

Figure B1. Lead under water quality (1) conditions.

Counts of Differences (Row Variable Greater Than Column)

	WQ2WT1	WQ2WT2	WQ2WT3	WQ2WT3
WQ2WT1	0	18	18	20
WQ2WT2	2	0	12	7
WQ2WT3	2	5	0	4
WQ2WT4	0	11	15	0

Z = (Sum of Signed Ranks)/Square Root (Sum of Squared Ranks)

	WQ2WT1	WQ2WT2	WQ2WT3	WQ2WT3
WQ2WT1	0.0000			
WQ2WT2	-2.9870	0.0000		
WQ2WT3	-2.9500	-0.8530	0.0000	
WQ2WT4	-3.9220	-0.5660	1.0070	0.0000

Two-Sided Probability Using Normal Approximation

	WQ2WT1	WQ2WT2	WQ2WT3	WQ2WT3
WQ2WT1	1.0000			
WQ2WT2	0.0030	1.0000		
WQ2WT3	0.0030	0.3940	1.0000	
WQ2WT4	0.0000	0.5710	0.3140	1.0000

18 Water Quality 2, Water treatment 1 lead values were greater than Water Quality 2, Water Treatment 2 values,
2 Water Quality 2, Water treatment 2 lead values were greater than Water Quality 2, Water Treatment 1 values,

18 Water Quality 2, Water treatment 1 lead values were greater than Water Quality 2, Water Treatment 3 values,
2 Water Quality 2, Water treatment 3 lead values were greater than Water Quality 2, Water Treatment 1 values,

20 Water Quality 2, Water treatment 1 lead values were greater than Water Quality 2, Water Treatment 4 values,
0 Water Quality 2, Water treatment 4 lead values were greater than Water Quality 2, Water Treatment 1 values,

12 Water Quality 2, Water treatment 2 lead values were greater than Water Quality 2, Water Treatment 3 values,
5 Water Quality 2, Water treatment 3 lead values were greater than Water Quality 2, Water Treatment 2 values,

7 Water Quality 2, Water treatment 2 lead values were greater than Water Quality 2, Water Treatment 4 values,
11 Water Quality 2, Water treatment 4 lead values were greater than Water Quality 2, Water Treatment 2 values,

4 Water Quality 2, Water treatment 3 lead values were greater than Water Quality 2, Water Treatment 4 values,
15 Water Quality 2, Water treatment 4 lead values were greater than Water Quality 2, Water Treatment 3 values,

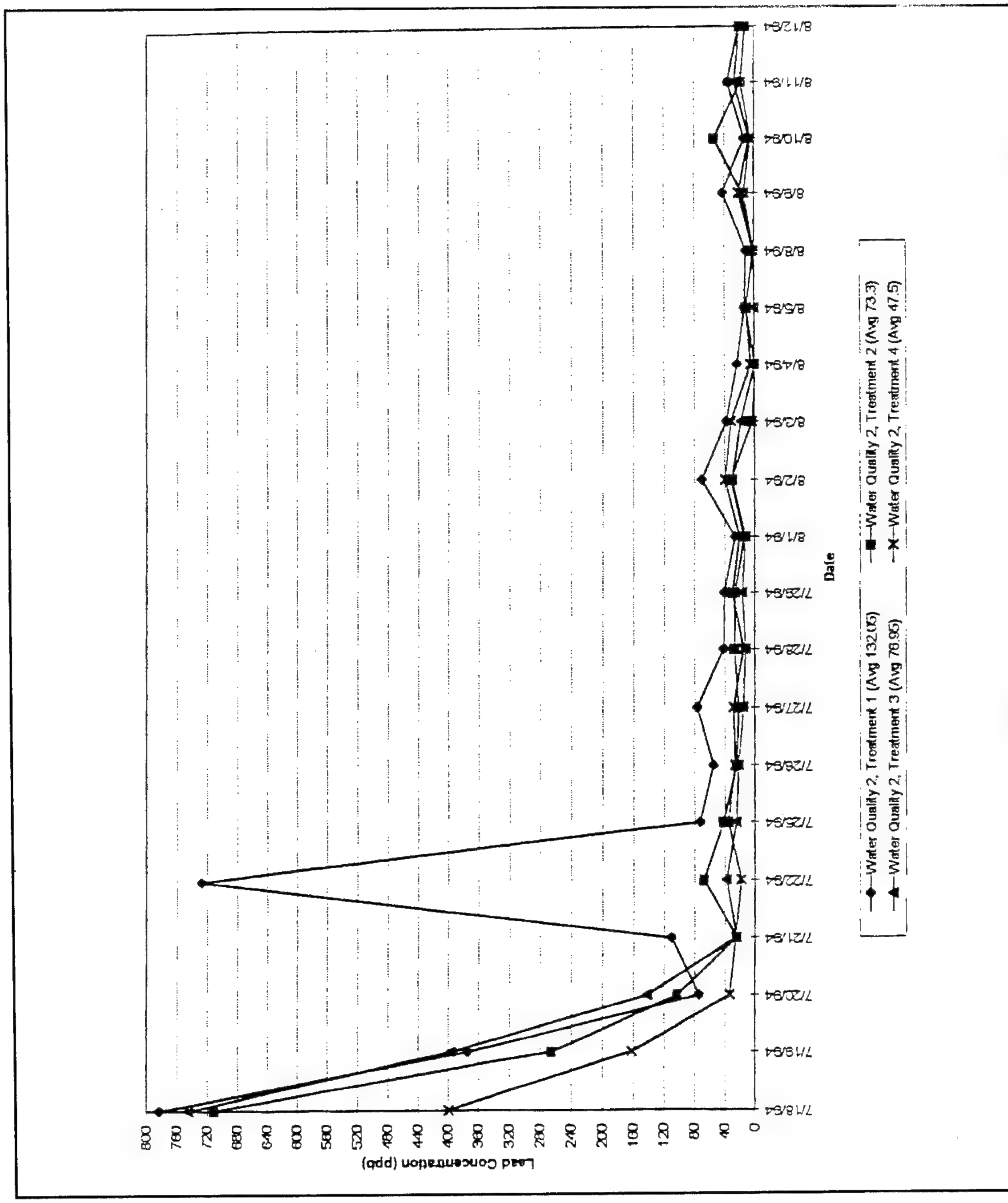

Figure B2. Lead under water quality (2) conditions.

Counts of Differences (Row Variable Greater Than Column)

	WQ3WT1	WQ3WT2	WQ3WT3	WQ3WT3
WQ3WT1	0	0	10	2
WQ3WT2	20	0	19	17
WQ3WT3	10	1	0	2
WQ3WT4	18	3	18	0

Z = (Sum of Signed Ranks)/Square Root (Sum of Squared Ranks)

	WQ3WT1	WQ3WT2	WQ3WT3	WQ3WT3
WQ3WT1	0.0000			
WQ3WT2	3.9200	0.0000		
WQ3WT3	-0.1680	-3.8830	0.0000	
WQ3WT4	3.1360	-3.0610	3.5470	0.0000

Two-Sided Probability Using Normal Approximation

	WQ3WT1	WQ3WT2	WQ3WT3	WQ3WT3
WQ3WT1	1.0000			
WQ3WT2	0.0000	1.0000		
WQ3WT3	0.8670	0.0000	1.0000	
WQ3WT4	0.0020	0.0020	0.0000	1.0000

0 Water Quality 3, Water treatment 1 lead values were greater than Water Quality 3, Water Treatment 2 values,
20 Water Quality 3, Water treatment 2 lead values were greater than Water Quality 3, Water Treatment 1 values,

10 Water Quality 3, Water treatment 1 lead values were greater than Water Quality 3, Water Treatment 3 values,
10 Water Quality 3, Water treatment 3 lead values were greater than Water Quality 3, Water Treatment 1 values,

2 Water Quality 3, Water treatment 1 lead values were greater than Water Quality 3, Water Treatment 4 values,
18 Water Quality 3, Water treatment 4 lead values were greater than Water Quality 3, Water Treatment 1 values,

19 Water Quality 3, Water treatment 2 lead values were greater than Water Quality 3, Water Treatment 3 values,
1 Water Quality 3, Water treatment 3 lead values were greater than Water Quality 3, Water Treatment 2 values,

17 Water Quality 3, Water treatment 2 lead values were greater than Water Quality 3, Water Treatment 4 values,
3 Water Quality 3, Water treatment 4 lead values were greater than Water Quality 3, Water Treatment 2 values,

2 Water Quality 3, Water treatment 3 lead values were greater than Water Quality 3, Water Treatment 4 values,
18 Water Quality 3, Water treatment 4 lead values were greater than Water Quality 3, Water Treatment 1 values,

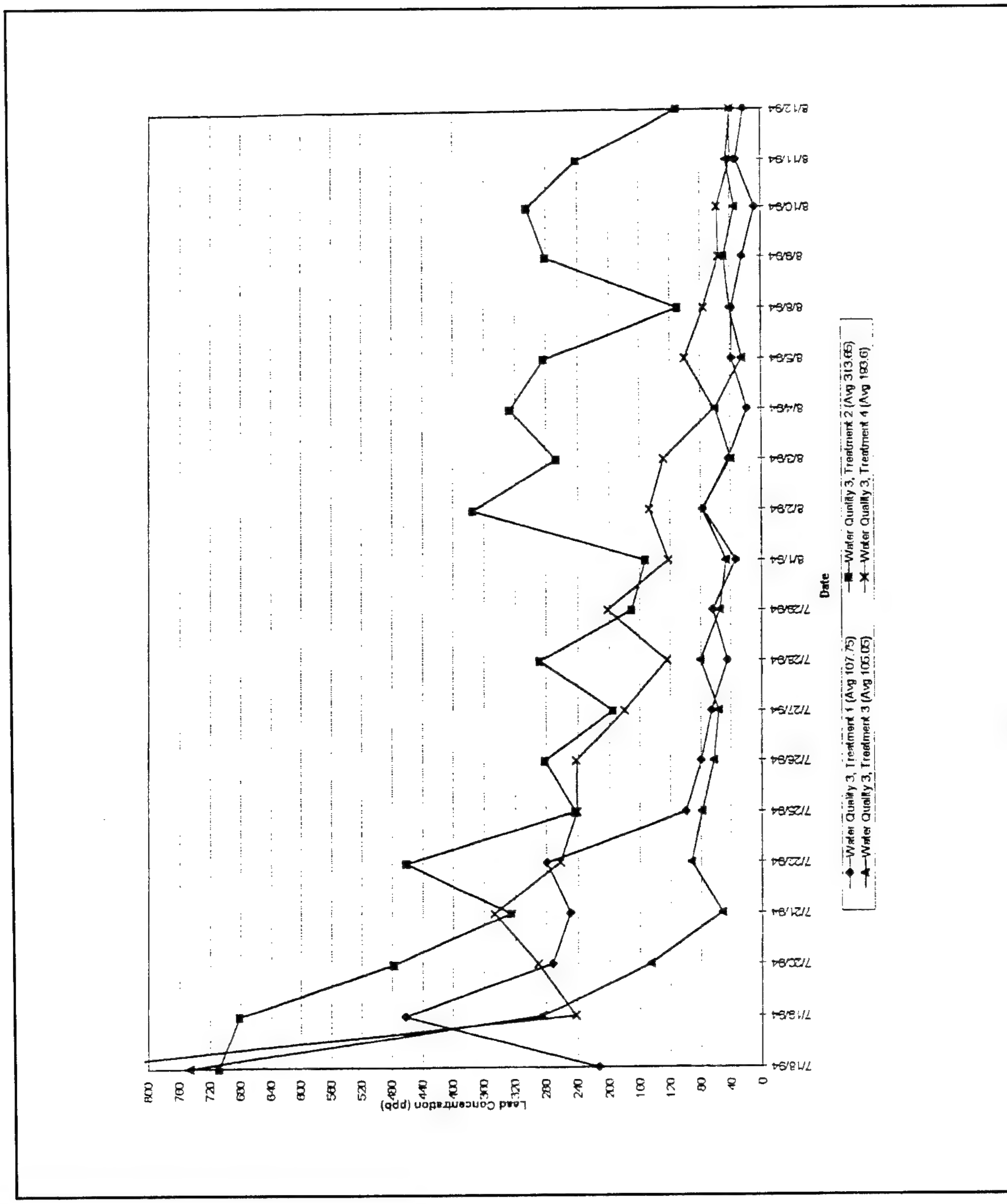

Figure B3. Lead under water quality (3) conditions.

Counts of Differences (Row Variable Greater Than Column)

	WQ4WT1	WQ4WT2	WQ4WT3	WQ4WT3
WQ4WT1	0	12	20	2
WQ4WT2	8	0	30	6
WQ4WT3	0	0	0	1
WQ4WT4	18	14	19	0

Z = (Sum of Signed Ranks)/Square Root (Sum of Squared Ranks)

	WQ4WT1	WQ4WT2	WQ4WT3	WQ4WT3
WQ4WT1	0.0000			
WQ4WT2	-0.9150	0.0000		
WQ4WT3	-3.9210	-3.9210	0.0000	
WQ4WT4	2.5760	1.6060	3.8830	0.0000

Two-Sided Probability Using Normal Approximation

	WQ4WT1	WQ4WT2	WQ4WT3	WQ4WT3
WQ4WT1	1.0000			
WQ4WT2	0.3600	1.0000		
WQ4WT3	0.0000	0.0000	1.0000	
WQ4WT4	0.0100	0.1080	0.0000	1.0000

12 Water Quality 4, Water treatment 1 lead values were greater than Water Quality 4, Water Treatment 2 values,
8 Water Quality 4, Water treatment 2 lead values were greater than Water Quality 4, Water Treatment 1 values,

20 Water Quality 4, Water treatment 1 lead values were greater than Water Quality 4, Water Treatment 4 values,
0 Water Quality 4, Water treatment 3 lead values were greater than Water Quality 4, Water Treatment 1 values,

2 Water Quality 4, Water treatment 1 lead values were greater than Water Quality 4, Water Treatment 4 values,
18 Water Quality 4, Water treatment 4 lead values were greater than Water Quality 4, Water Treatment 1 values,

20 Water Quality 4, Water treatment 2 lead values were greater than Water Quality 4, Water Treatment 3 values,
0 Water Quality 4, Water treatment 3 lead values were greater than Water Quality 4, Water Treatment 2 values,

6 Water Quality 4, Water treatment 2 lead values were greater than Water Quality 4, Water Treatment 4 values,
14 Water Quality 4, Water treatment 4 lead values were greater than Water Quality 4, Water Treatment 2 values,

1 Water Quality 4, Water treatment 3 lead values were greater than Water Quality 4, Water Treatment 4 values,
19 Water Quality 4, Water treatment 4 lead values were greater than Water Quality 4, Water Treatment 3 values,

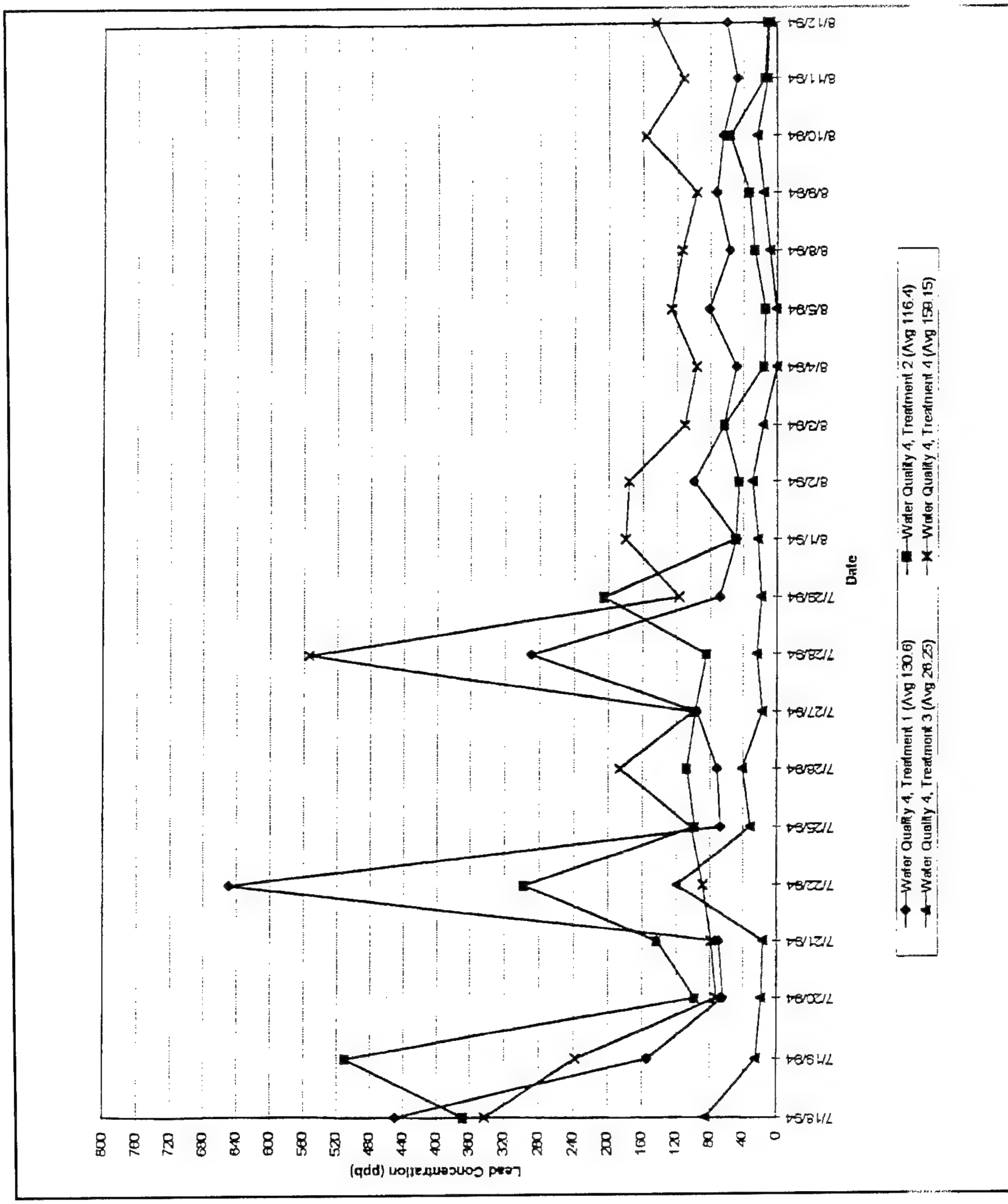

Figure B4. Lead under water quality (4) conditions.

Counts of Differences (Row Variable Greater Than Column)

	WQ5WT1	WQ5WT2	WQ5WT3	WQ5WT3
WQ5WT1	0	4	17	4
WQ5WT2	16	0	19	12
WQ5WT3	3	0	0	0
WQ5WT4	16	8	20	0

Z = (Sum of Signed Ranks)/Square Root (Sum of Squared Ranks)

	WQ5WT1	WQ5WT2	WQ5WT3	WQ5WT3
WQ5WT1	0.0000			
WQ5WT2	1.8290	0.0000		
WQ5WT3	-2.8750	-3.8230	0.0000	
WQ5WT4	2.2780	-0.5600	3.9200	0.0000

Two-Sided Probability Using Normal Approximation

	WQ5WT1	WQ5WT2	WQ5WT3	WQ5WT3
WQ5WT1	1.0000			
WQ5WT2	0.0670	1.0000		
WQ5WT3	0.0040	0.0000	1.0000	
WQ5WT4	0.0230	0.5750	0.0000	1.0000

4 Water Quality 5, Water treatment 1 lead values were greater than Water Quality 5, Water Treatment 2 values,
16 Water Quality 5, Water treatment 2 lead values were greater than Water Quality 5, Water Treatment 1 values,

17 Water Quality 5, Water treatment 1 lead values were greater than Water Quality 5, Water Treatment 3 values,
3 Water Quality 5, Water treatment 3 lead values were greater than Water Quality 5, Water Treatment 1 values,

4 Water Quality 5, Water treatment 1 lead values were greater than Water Quality 5, Water Treatment 4 values,
16 Water Quality 5, Water treatment 4 lead values were greater than Water Quality 5, Water Treatment 1 values,

19 Water Quality 5, Water treatment 2 lead values were greater than Water Quality 5, Water Treatment 3 values,
0 Water Quality 5, Water treatment 3 lead values were greater than Water Quality 5, Water Treatment 2 values,

12 Water Quality 5, Water treatment 2 lead values were greater than Water Quality 5, Water Treatment 4 values,
8 Water Quality 5, Water treatment 4 lead values were greater than Water Quality 5, Water Treatment 2 values,

0 Water Quality 5, Water treatment 3 lead values were greater than Water Quality 5, Water Treatment 4 values,
20 Water Quality 5, Water treatment 4 lead values were greater than Water Quality 5, Water Treatment 3 values,

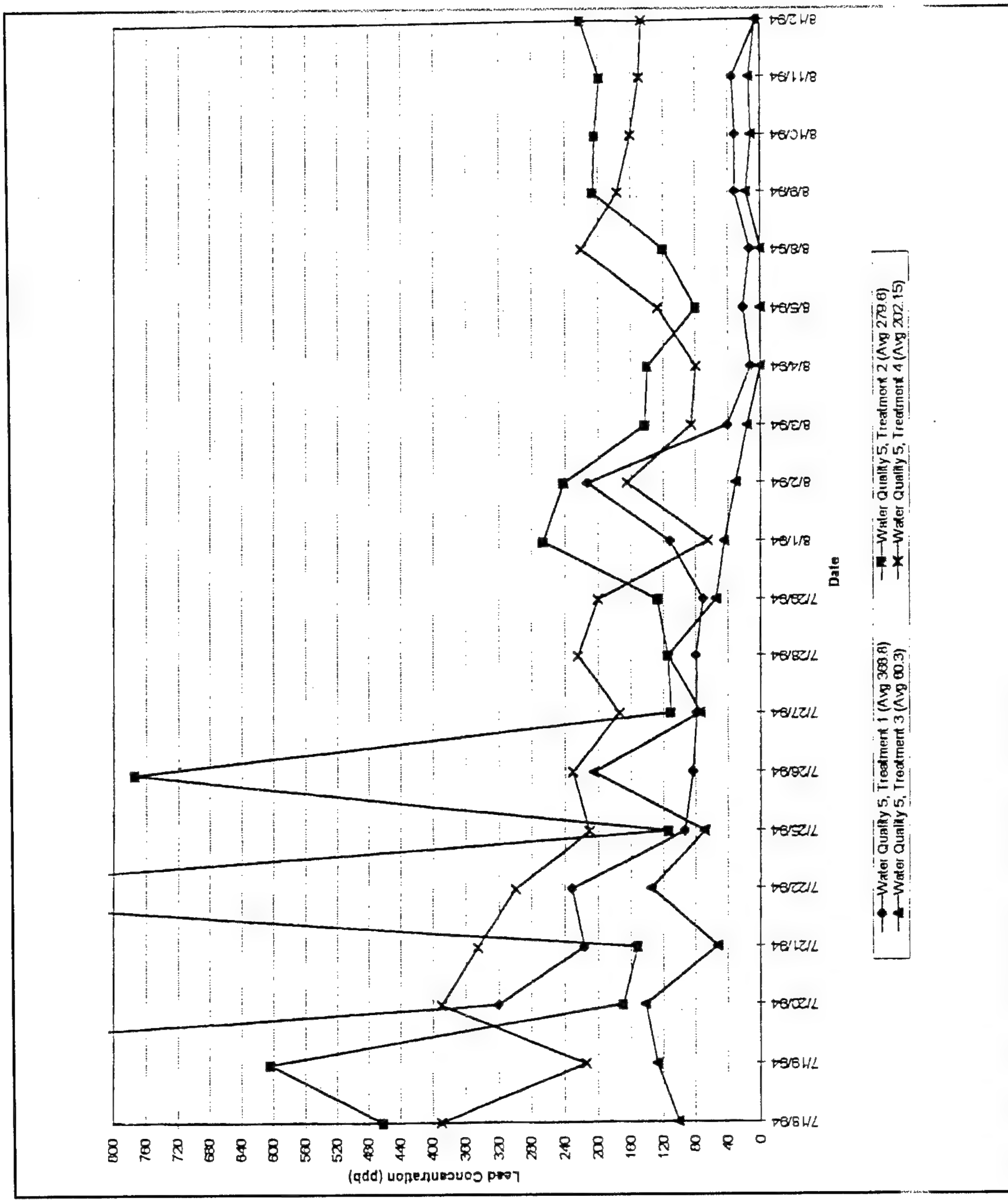

Figure B5. Lead under water quality (5) conditions.

Counts of Differences (Row Variable Greater Than Column)

	WQ6WT1	WQ6WT2	WQ6WT3	WQ6WT3
WQ6WT1	0	4	11	4
WQ6WT2	16	0	19	14
WQ6WT3	9	1	0	2
WQ6WT4	16	6	18	0

Z = (Sum of Signed Ranks)/Square Root (Sum of Squared Ranks)

	WQ6WT1	WQ6WT2	WQ6WT3	WQ6WT3
WQ6WT1	0.0000			
WQ6WT2	2.2030	0.0000		
WQ6WT3	-1.3260	-3.8830	0.0000	
WQ6WT4	1.9790	-1.3440	2.7250	0.0000

Two-Sided Probability Using Normal Approximation

	WQ6WT1	WQ6WT2	WQ6WT3	WQ6WT3
WQ6WT1	1.0000			
WQ6WT2	0.0280	1.0000		
WQ6WT3	0.1850	0.0000	1.0000	
WQ6WT4	0.0480	0.1790	0.0060	1.0000

4 Water Quality 6, Water treatment 1 lead values were greater than Water Quality 6, Water Treatment 2 values,
16 Water Quality 6, Water treatment 2 lead values were greater than Water Quality 6, Water Treatment 1 values,

11 Water Quality 6, Water treatment 1 lead values were greater than Water Quality 6, Water Treatment 3 values,
9 Water Quality 6, Water treatment 3 lead values were greater than Water Quality 6, Water Treatment 1 values,

4 Water Quality 6, Water treatment 1 lead values were greater than Water Quality 6, Water Treatment 4 values,
16 Water Quality 6, Water treatment 4 lead values were greater than Water Quality 6, Water Treatment 1 values,

19 Water Quality 6, Water treatment 2 lead values were greater than Water Quality 6, Water Treatment 3 values,
1 Water Quality 6, Water treatment 3 lead values were greater than Water Quality 6, Water Treatment 2 values,

14 Water Quality 6, Water treatment 2 lead values were greater than Water Quality 6, Water Treatment 4 values,
6 Water Quality 6, Water treatment 4 lead values were greater than Water Quality 6, Water Treatment 2 values,

2 Water Quality 6, Water treatment 3 lead values were greater than Water Quality 6, Water Treatment 4 values,
18 Water Quality 6, Water treatment 4 lead values were greater than Water Quality 6, Water Treatment 3 values,

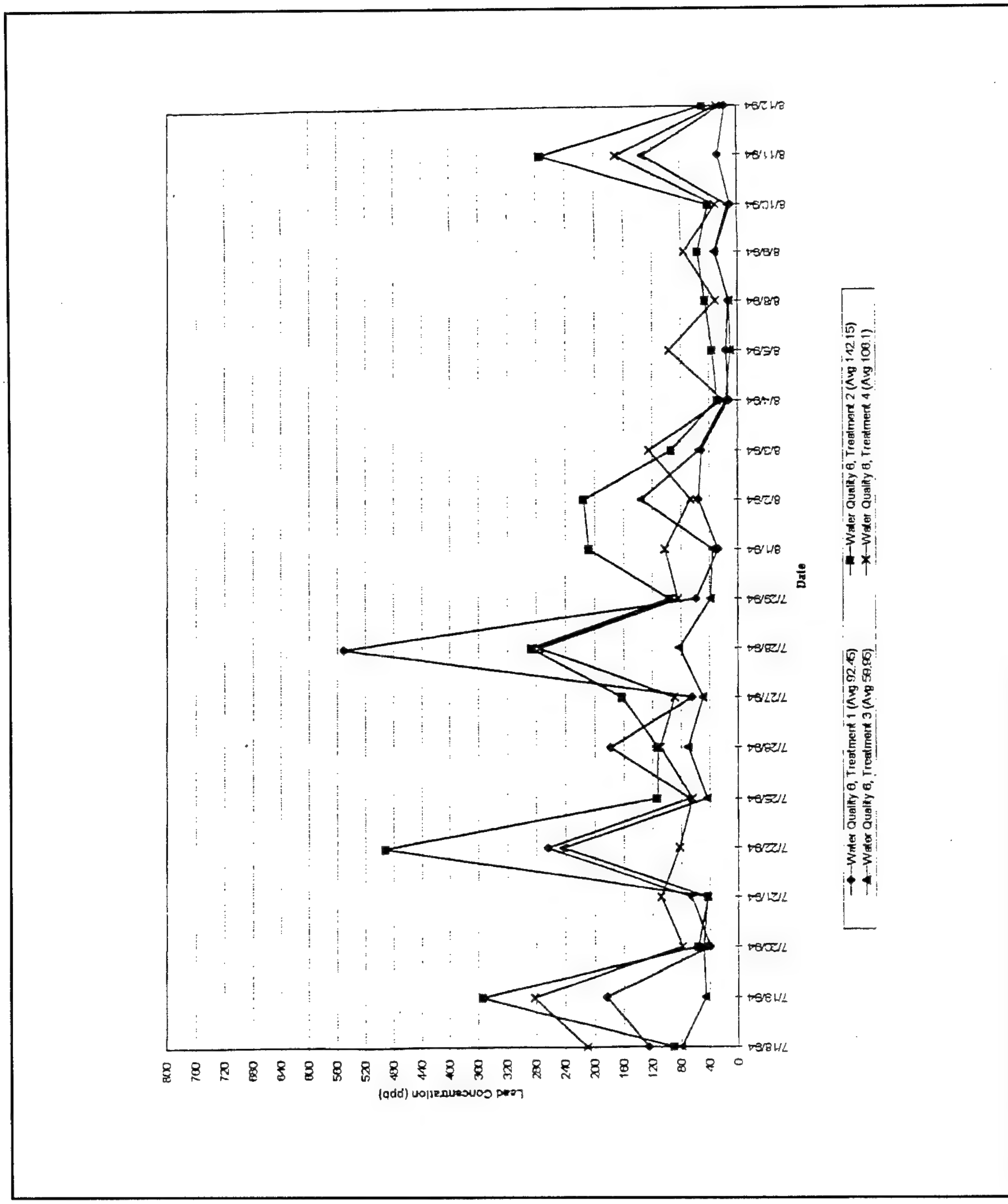

Figure B6. Lead under water quality (6) conditions.

Counts of Differences (Row Variable Greater Than Column)

	WQ7WT1	WQ7WT2	WQ7WT3	WQ7WT3
WQ7WT1	0	4	12	0
WQ7WT2	16	0	18	7
WQ7WT3	7	2	0	2
WQ7WT4	20	12	18	0

Z = (Sum of Signed Ranks)/Square Root (Sum of Squared Ranks)

	WQ7WT1	WQ7WT2	WQ7WT3	WQ7WT3
WQ7WT1	0.0000			
WQ7WT2	3.2110	0.0000		
WQ7WT3	-0.8860	-2.6140	0.0000	
WQ7WT4	3.9200	1.4490	3.1360	0.0000

Two-Sided Probability Using Normal Approximation

	WQ7WT1	WQ7WT2	WQ7WT3	WQ7WT3
WQ7WT1	1.0000			
WQ7WT2	0.0010	1.0000		
WQ7WT3	0.3760	0.0090	1.0000	
WQ7WT4	0.0000	0.1470	0.0020	1.0000

4 Water Quality 7, Water treatment 1 lead values were greater than Water Quality 7, Water Treatment 2 values,
16 Water Quality 7, Water treatment 2 lead values were greater than Water Quality 7, Water Treatment 1 values,

11 Water Quality 7, Water treatment 1 lead values were greater than Water Quality 7, Water Treatment 3 values,
9 Water Quality 7, Water treatment 3 lead values were greater than Water Quality 7, Water Treatment 1 values,

4 Water Quality 7, Water treatment 1 lead values were greater than Water Quality 7, Water Treatment 4 values,
16 Water Quality 7, Water treatment 4 lead values were greater than Water Quality 7, Water Treatment 1 values,

19 Water Quality 7, Water treatment 2 lead values were greater than Water Quality 7, Water Treatment 3 values,
1Water Quality 7, Water treatment 3 lead values were greater than Water Quality 7, Water Treatment 2 values,

14 Water Quality 7, Water treatment 2 lead values were greater than Water Quality 7, Water Treatment 4 values,
6 Water Quality 7, Water treatment 4 lead values were greater than Water Quality 7, Water Treatment 2 values,

2 Water Quality 7, Water treatment 3 lead values were greater than Water Quality 7, Water Treatment 4 values,
18 Water Quality 7, Water treatment 4 lead values were greater than Water Quality 7, Water Treatment 3 values,

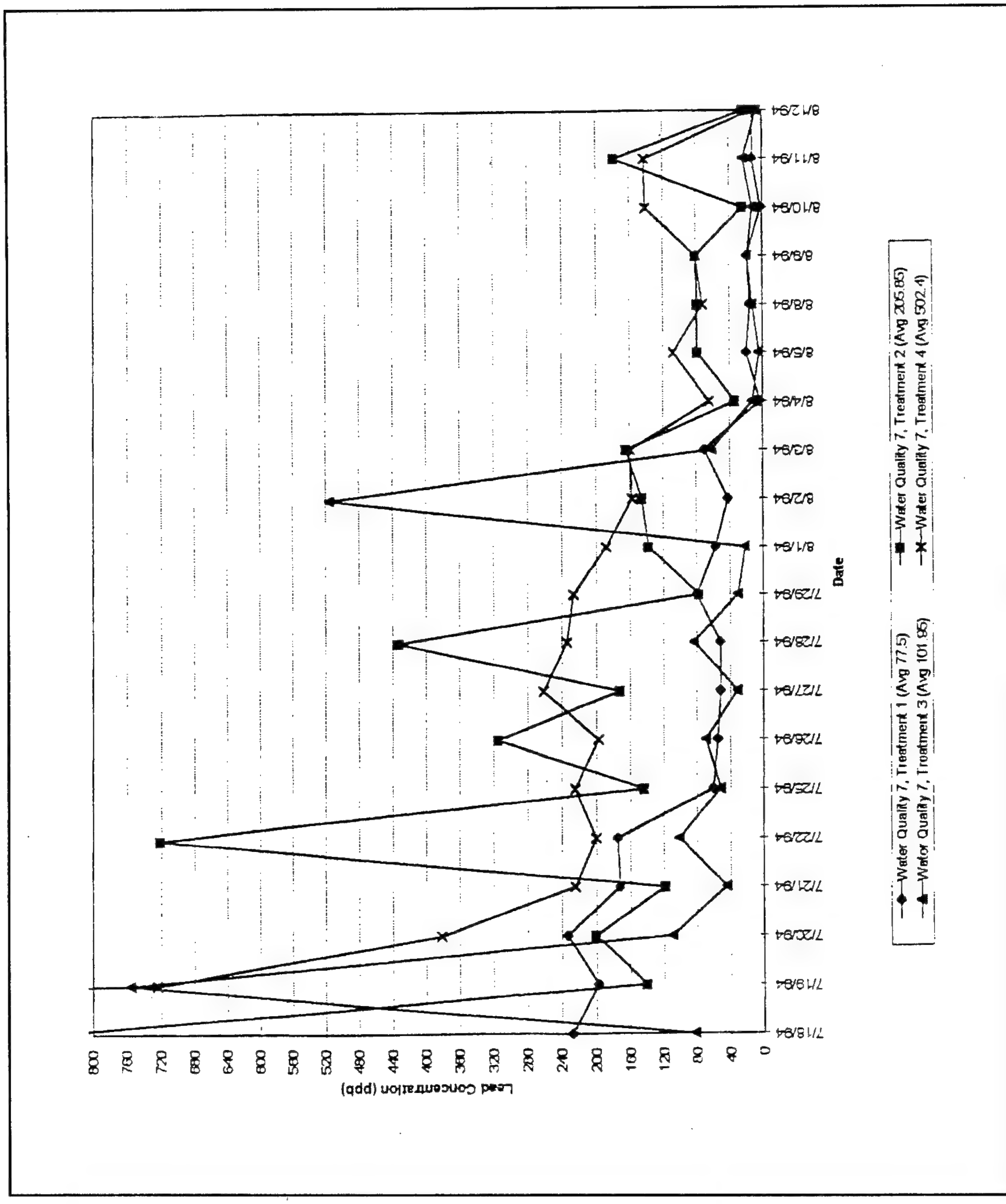

Figure B7. Lead under water quality (7) conditions.

Counts of Differences (Row Variable Greater Than Column)

	WQ8WT1	WQ8WT2	WQ8WT3	WQ8WT3
WQ8WT1	0	8	19	11
WQ8WT2	12	0	18	11
WQ8WT3	1	2	0	1
WQ8WT4	9	8	19	0

Z = (Sum of Signed Ranks)/Square Root (Sum of Squared Ranks)

	WQ8WT1	WQ8WT2	WQ8WT3	WQ8WT3
WQ8WT1	0.0000			
WQ8WT2	-0.2240	0.0000		
WQ8WT3	-3.8460	-3.3970	0.0000	
WQ8WT4	-0.9150	-0.9460	3.7910	0.0000

Two-Sided Probability Using Normal Approximation

	WQ8WT1	WQ8WT2	WQ8WT3	WQ8WT3
WQ8WT1	1.0000			
WQ8WT2	0.8230	1.0000		
WQ8WT3	0.0000	0.0010	1.0000	
WQ8WT4	0.3600	0.3440	0.0000	1.0000

8 Water Quality 8, Water treatment 1 lead values were greater than Water Quality 8, Water Treatment 1 values,
12 Water Quality 8, Water treatment 2 lead values were greater than Water Quality 8, Water Treatment 2 values,

19 Water Quality 8, Water treatment 1 lead values were greater than Water Quality 8, Water Treatment 3 values,
1 Water Quality 8, Water treatment 3 lead values were greater than Water Quality 8, Water Treatment 1 values,

11 Water Quality 8, Water treatment 1 lead values were greater than Water Quality 8, Water Treatment 4 values,
9 Water Quality 8, Water treatment 4 lead values were greater than Water Quality 8, Water Treatment 1 values,

18 Water Quality 8, Water treatment 2 lead values were greater than Water Quality 8, Water Treatment 3 values,
2 Water Quality 8, Water treatment 3 lead values were greater than Water Quality 8, Water Treatment 2 values,

11 Water Quality 8, Water treatment 2 lead values were greater than Water Quality 8, Water Treatment 4 values,
8 Water Quality 8, Water treatment 4 lead values were greater than Water Quality 8, Water Treatment 2 values,

1 Water Quality 8, Water treatment 3 lead values were greater than Water Quality 8, Water Treatment 4 values,
19 Water Quality 8, Water treatment 4 lead values were greater than Water Quality 8, Water Treatment 3 values.

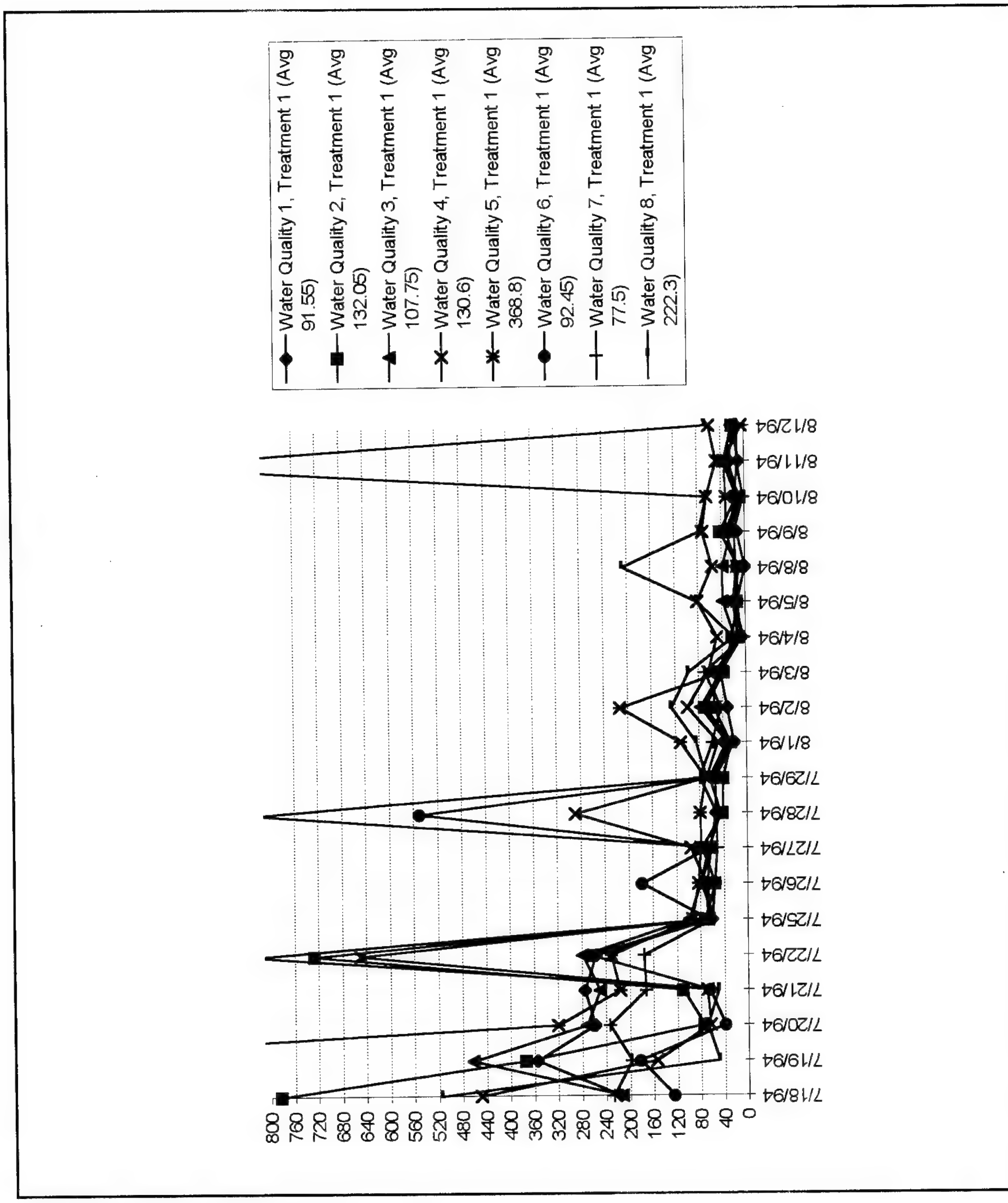

Figure B8. Lead under water quality (8) conditions.

Appendix C: DRAFT Public Works Technical Bulletin No. 420-46-07

DEPARTMENT OF THE ARMY
U.S. Army Center for Public Works
7701 Telegraph Road
Alexandria, VA 22315-3862

Public Works Technical Bulletin (Revised 03/24/95)
No. 420-46-07

FACILITY ENGINEERING
MAINTENANCE AND REPAIR

CHEMICAL TREATMENT OF DOMESTIC WATER TO INHIBIT
DISSOLUTION OF LEAD IN BUILDING PLUMBING

1. Purpose. This Public Works Technical Bulletin (PWTB) provides information on selection and application of chemical additives to inhibit the dissolution of lead in drinking water.

2. Applicability. This PWTB applies to all U.S. Army Directorate of Public Works activities.

3. References.

a. Lead and Copper Rule Guidance Manual Volumes I, II, U.S. Environmental Protection Agency, EPA 811-B-92-001,002, Sept. 1992.
b. Maintenance and Operation of Water Supply, Treatment, and Distribution Systems, TM 5-660, 30 August 1984.
c. Radon Removal Techniques for Small Community Public Water Supplies, EPA/600/2-90/036, NTIS PB90-257809.
d. Development and Testing of an Anti-Scale/Corrosion Resistant Coating for Domestic Hot Water Heat Exchangers, Hock, V. F. et al., USACERL Technical Report M-91/05, December, 1990.
e. Drinking Water Treatment Optimization Using the Pipe-Loop System: Demonstration at Aberdeen Proving Ground, MD, Temkar P. M., et al., USACERL Technical Report N-90/05, U.S. Army Corps of Engineers, Construction Engineering Research Laboratory, June 1990.
f. Lead Control Strategies, AWWA Research Foundation and American Water Works Association, 1990.

4. Discussion.

A. Introduction

This bulletin is intended to provide guidance on selection of candidate inhibitor treatments for control of lead in drinking water in accordance with the Safe Drinking Water Act (SDWA) and the USEPA's National Primary Drinking Water Regulations (40 CFR 141 and 142). This guidance is based on literature and laboratory investigations conducted by USACERL with the assistance of the Illinois State Water Survey, and the Environmental Protection Agency, Risk Reduction Engineering Laboratory.

B. Background

A variety of chemical treatment approaches are available for control of lead in water. Among the common examples are: (1) Manipulation of water quality to deposit a barrier film of calcium carbon, (2) Adjustment of pH, Dissolved Inorganic Carbonate (DIC) and alkalinity to develop a passive film of basic lead carbonate or lead carbonate, and (3) Chemical inhibitor addition aimed at producing passive films over the piping interior. Passive pipe wall films induced by addition of phosphates or silicates inhibit the dissolution of lead and copper.

The deposition of calcium carbonate can be difficult to control especially at the far reaches of the system. Water quality manipulation can require considerable maintenance and careful monitoring. In comparison to this approach, addition of chemical inhibitors such as phosphates and silicates and pH/alkalinity adjustment are relatively simple to execute. The guidance provided herein is focused on these three approaches for control of lead in water.

C. Treatment Selection

A variety of chemical treatment options are available. No one treatment is feasible for all water qualities. The following sections provide guidance for the selection of a given treatment option for control of lead.

1. pH/DIC/Alkalinity Adjustment

Figure 1 contains a shaded region of pH and DIC that yields acceptable levels of lead. To obtain an acceptable level of lead, the pH and DIC must be selected from this chart. Within this region, the minimal lead level occurs at pH = 9.8 and DIC = 4.8 mg/L. In practice however, it is recommended that DIC = 10 mg/L or slightly above to ensure proper buffering of the pH. Apart from this issue, a pH above 9.0 is well above the feasible limit for many water distribution systems. This limitation can be due to potential impacts on taste, odor, scale formation, and disinfection efficiency

and may thus eliminate this approach for lead control for many applications.

It is important to ensure that the alkalinity is sufficient to ensure a stable pH. The relationship between the DIC, pH, and Alkalinity is given in Appendix Figures 2A-2H. The value "I" in these figures stands for ionic strength which serves as a measure of conductivity. The (I) of a given water may be estimated from either the conductivity (CON) or the total dissolved solids (TDS) as follows:

$$I = 2.6 \times 10^{-5} \text{ CON (umho/cm), or}$$

$$I = 2.5 \times 10^{-5} \text{ TDS (mg/L).}$$

After the pH and DIC are selected to control lead, the alkalinity must be checked to ensure it is above 25 mg/L to ensure proper pH buffering.

For relatively soft ground waters, the simplest way of increasing the pH is by installation of aeration or some other non-chemical means of removing CO_2. Reference (a), provides guidance on use of filters for iron and manganese removal and related purposes. Prior to adjustment of pH, it is recommended that analysis of system chemistry be conducted to determine if the pH adjustment will cause precipitation of $CaCO_3$, iron, or manganese. Any treatment should be jar tested to assess impact on pH and other water quality parameters as described in Reference (a). To avoid potential film instability, any treatment that will involve pH adjustment of more than 0.2 pH units should be phased in at rate of 10% the total adjustment per week.

2. Phosphates

There are a myriad of phosphate products available for control of plumbosolvency (i.e., the solubility of lead). Polyphosphates (PPs) are generally well suited for forming high solubility complexes with various metal ions. However, orthophosphates (OPs) offer superior control of lead corrosion by forming a lead phosphate precipitate film. Zinc, Potassium, or Sodium typically accompany most OP formulations. Potassium and Sodium ions generally pass through the system leaving the OP in the passive films. (Zinc may or may not be incorporated into the film depending upon the water quality.) Figure 3 contains a shaded region of pH and DIC in which OP controls lead. The use of OP for lead control is best suited to waters of low hardness and a pH range of 7.2 to 7.8. The most effective lead reducing range for OP application is pH = 7.5 to 7.6. Above pH = 8.0, OP is not recommended. OP dosages of 4 to 5 mg/L are

recommended for most systems. To select the pH and alkalinity for optimal lead control, consult Figures 4A-4F. Once a pH and alkalinity (>25mg/L) have been selected, refer to Appendix Figures 2A-2H to ensure that the DIC for this selection is at least 10 mg/L to ensure proper pH buffering. Buffering can be increased by dosing with sodium bicarbonate.

When choosing a phosphate it is recommended that the formulation providing the greatest concentration (mg/L) of orthophosphate be selected. The zinc, potassium, or sodium associated with the formulation should be selected based on review of state or local drinking and wastewater regulations. In some cases, selection of Zn-OP may provide a high quality drinking water while resulting in a unacceptable waste water in violation of state regulations due to zinc levels.

Blends of PP and OP may also be used to control lead in waters that contain a variety of other metals. Care must be taken in selecting the phosphate dosage that takes into account all metal ions present which may compete with the lead for phosphate. The typical phosphate order of affinity is as follows: manganese, iron, copper, aluminum, zinc, lead, calcium, and others. This order may vary from one phosphate formulation to another. An effective addition of a OP-PP phosphate blend must be dosed so that sufficient OP is applied to control lead while the PP controls the other metals in the system. Verification of sufficient OP dosage is discussed in the following section.

To expedite film formation, it is recommended that initially the OP dose be applied at 10 mg/L. The initial dosage should be maintained until approximately 90% or more of the recommended orthophosphate concentration is maintained throughout the farthest reaches of the system. Additionally, pH and chlorine residuals should remain stable. After those conditions are achieved, the OP feed dosage may be reduced to 4-5 mg/L. This process may take several months.

Iron and manganese may both be present in source well waters. Previous adjustments to account for these species may be affected by treatment adjustments for lead. For example, a given system that is being treated to control iron or manganese may form deposits due to chemical adjustment of pH intended for control of lead. It is recommended that these metals be removed prior to treatment for lead. Appropriate technologies for removal of iron and manganese include filtration and/or aeration. Reference (b) is a general source for specific iron and manganese removal information (Sections 6-10 and 6-11). Reference (c) also provides information on use of these technologies for removal of iron and manganese. Where filtering or aeration to reduce pH is unfeasible, a blend of OP and PP may be

applied. As noted earlier, the OP may be dosed to control the lead and the PP may be dosed to accommodate all the other metals anticipated to precipitate due to the change in water quality.

3. Silicates

Silicates can be used to control lead as well as iron, manganese and other metals. Formulations generally come with a 28-30% content of SiO_2 in combination with some amount of Na_2O. These formulations are represented generically as $Na_2O.xSiO_2$ where "x" varies from 1.6 to 3.2 for commercial products. Such formulations can bring lead levels under control in time frames ranging from 2 weeks to 6 months depending upon pH and alkalinity. This treatment is recommended for pH values greater than 8.0. It is recommended that the formulation offering the highest ratio of SiO_2/NaO_2 be selected unless an increase in pH is desired. Initial dosage should be in the range of 20-25 mg/L above the baseline level of silicate in the water. This initial dosage should be maintained until approximately 90% or more of the silicate concentration is reached throughout the system. pH and chlorine residuals should also be permitted to stabilize prior to adjusting the silicate feed to a maintenance level. After these conditions are achieved, a maintenance dosage of 10-15 mg/L may be used. These formulations may raise pH especially in poorly buffered waters. Alkalinity should be raised to 65-70 mg/L by addition of sodium bicarbonate to increase buffering capacity.

4. Treatment Selection Guide

The Table 1 summaries the chemical treatment options and recommendations for control of lead in drinking water.

Table 1

Chemical Treatment Options and Recommendations

Treatment	pH Range	Other Requirements	
Silicate	> or = 8.0	Alkalinity	= 65 - 70 mg/L
		Initial Dose	= 20 - 25
		Maintenance Dose	= 15 - 20
Zinc Orthophosphate	7.2 - 7.8	Alkalinity	> 25 mg/L
		DIC	> 10 - 15 mg/L
		Initial Dose	= 10 mg/L
		Maintenance Dose	= 3 - 5 mg/L
pH/DIC/Alkalinity	9 - 10	Alkalinity	= 65 -100 mg/L
		DIC	> 10 - 15 mg/L

5. Secondary Impacts

A variety of potential secondary impacts are associated with treating water for control of lead. Some of these possibilities involve effects on: (1) biofilm growth, (2) coliforms, (3) bacterial plate counts, (4) waste water effluent, and (5) disinfection by products. In addition to these considerations there may exist the potential for forming mineral scales on heat exchangers. See Reference (d) or contact the U.S. Army Center for Public Works for information on phenolic coatings that may be used to mitigate this problem. If the treatment facility uses a coagulation process involving alum there is potential for the formation of aluminum-phosphate deposits. To mitigate this effect, the coagulation, flocculation, sedimentation process should be controlled to avoid carry over of alum into the output. Water quality parameters that effect this control are provided in Reference (f). Additional secondary impacts may include calcium carbonate precipitation and Zn induced turbidity. For control of calcium carbonate precipitation consult reference (a). Guidance for control of Zn induced turbidity is found in reference (f). The U.S. Army Center for Public Works may be consulted for questions on these and other secondary impacts. On occasion a water system may exhibit fluctuation in the lead levels. This occurrence is most likely due to disruption of the pipe wall oxide film. Lead level fluctuations can be avoided by eliminating sources of water hammer and by avoiding major changes in water quality--particularly pH, alkalinity, and hardness.

5. Implementation. The optimal treatment selection is a function of pH, alkalinity and other water quality parameters including other metal ions that can compete against lead for phosphates or silicates. Evaluation of various chemical treatments can be facilitated by application of the CERL Pipe Loop System™ as described in Reference (e). This tool is designed to draw system water and model actual system levels of lead and copper. The loop is suitable for the demonstration of chemical treatments for mitigation of lead and copper corrosion in accordance with 40 CFR 141.82 and guidance provided in volume II of Reference (a).

6. Point of Contact. Questions and/or comments regarding this subject that cannot be resolved at the installation or MACOM level should be directed to the U.S. Army Center for Public Works, Directorate of Engineering, CECPW-ES, 7701 Telegraph road, Alexandria, VA 22315-3862, at (703) 806-5194, DSN 656-5194 or PAXID CEHSCFUS or U.S. Army Construction Engineering Research Laboratories, Engineering and Materials Division, 2902 Newmark Drive, Champaign, IL 61826-9005, at (217) 373-6753.

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